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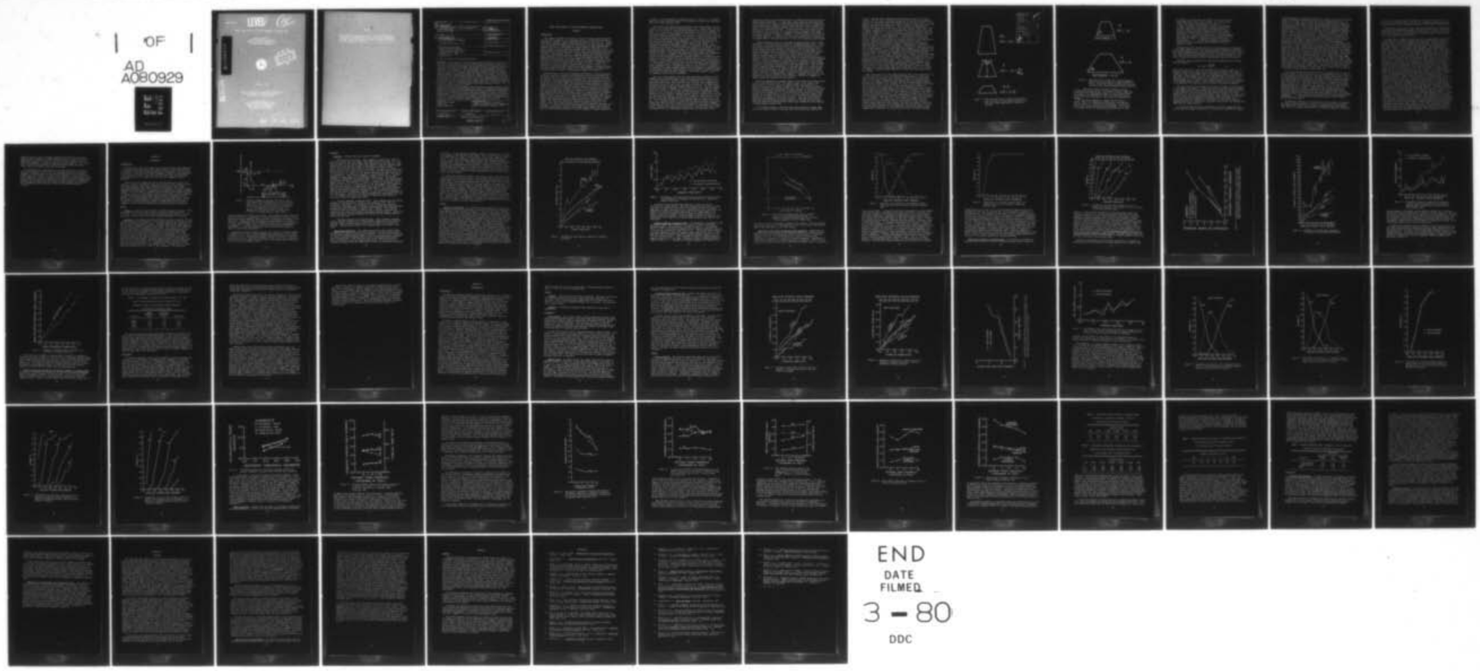

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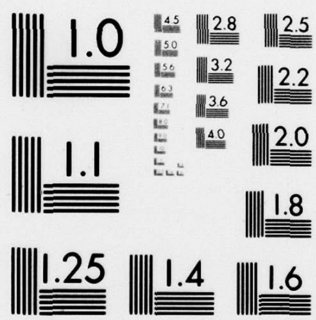

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16. Abstract

One cue for visual judgment of glidepath angle has been referred to as form ratio. Form ratio is defined as the ratio of vertical height of the runway to width of the far end in the runway retinal image. The ability of pilots to judge form ratios was compared with the ability to judge approach angles in the nighttime "black hole" situation in two experiments. In one experiment, 16 pilots observed a stationary model of a lighted airport runway under nighttime conditions at different simulated approach angles from a simulated distance of 8,000 ft from threshold. Pilots made verbal judgments of approach angle using the categories "low," "high," and "OK," and on half the trials also estimated form ratios. In the second experiment, 20 pilots made observations both in a similar static condition at simulated distances of 8,000 ft and 26,000 ft from threshold, and in a dynamic condition in which they controlled the model to produce (i) specified values of form ratio (1.0, 2.0, and 3.0) or (ii) a 3° approach angle, as the model approached them between 8,000 and 26,000 ft. The simulated approach speed was 125 knots.

Responses in both static and dynamic conditions indicated a general tendency to overestimate form ratios and approach angles less than 3°. Intersubject and intrasubject variability of form ratio and approach angle responses were comparable. These findings (i) do not support the utility of form ratio judgments as an aid in selecting approach angle, (ii) add to the empirical evidence of visual illusions and the danger of reliance on visual information for judgment of approach angle in the nighttime "black hole" situation where only runway lights are visible, and (iii) point to variability in perception of approach angle as an important part of the problem.

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RUNWAY IMAGE SHAPE AS A CUE FOR JUDGMENT OF APPROACH ANGLE

CHAPTER I

Introduction.

The dangerous tendency for pilots to fly too low during night approaches has long been attributed, on an anecdotal basis, to visual illusions due to reduction of available visual information at night (15,16,20,27,30). Studies of aircraft accidents emphasize the importance of the night approach problem with the finding of a high proportion of accidents in night approaches and landings that are not associated with adverse weather conditions (16,20). Recent research provides empirical evidence that visual illusions occur in the night approach situation which may directly cause low approaches during actual attempts to land at night (20,26). A recent study in this laboratory found that pilots overestimated angles of approach (glide path) simulated with a model runway by a factor of 2 (26). This overestimation means that, under nighttime conditions when only runway lights are visible, pilots may be at one-half the altitude that they think they are, and may be dangerously low in some cases in spite of judging their altitude to be safe. In addition to quantification of such visual illusions which can occur at night, it is desirable to understand what variables determine judgments of approach angle so that approach and runway lighting can be designed most effectively and so that pilots may be trained to judge approach angle more accurately.

Monocular visual cues are the important determiners of visual perception during the approach to landing since binocular cues such as stereopsis and convergence cannot be effective at the relatively great distances involved in all but the last few seconds of the approach (27). The monocular cues that are generally considered important are relative motion parallax and size and shape cues in the runway image; the latter may include perspective, height, or foreshortening of the runway image (15,16,28,31). Relative motion parallax is defined as a difference in rate of apparent movement of objects in the visual field. In approaches to landing, all objects in the approach scene appear to move directly away from the aim point toward which the aircraft is moving; this movement away from the aim point occurs in a complex pattern of apparent velocities which is a function of glide path angle and approach speed (11). However, three experiments in our laboratory (25,26) have found that relative motion parallax had little or no effect on perceived orientation of a model runway under simulated nighttime conditions when only runway lights were visible. No effect was observed at simulated distances as near as 1.33 nautical miles from runway threshold and at simulated speeds of approach up to 140 knots. It was also found that the presence of a stable visual frame of reference simulating the cockpit window frame did not enhance the effectiveness of relative motion parallax as a cue for judgment of runway orientation

at night. The overestimation of approach angle by a factor of 2, discussed above (26), also occurred in spite of the presence of motion cues resulting from the 140-knot approach speed.

The finding that relative motion parallax in the runway image is not an effective cue for perception of approach angle, nor of runway slant, does not reflect on the utility of relative motion parallax as a cue for judging aim point, i.e., the point on the ground toward which the aircraft is moving. A well known method of using judgments of aim point to control approach path is called the "gunsight" method (16). This method is based on the fact that the aim point on the ground toward which the aircraft is moving is stationary in the cockpit window during stable approaches. Points on the ground nearer than the aim point appear to move downward in the window and points on the ground beyond the aim point appear to move upward in the window. The "gunsight" technique is dependent, however, on constancy of the aircraft's attitude and the position of the pilot's eye relative to the window. In such a stable situation the pilot can align the intended touchdown point with the appropriate point on the window and fly at a constant angle of approach toward that point. Although stable approaches can be flown with "remarkable accuracy" using this technique, turbulence and windshear can render it useless and unnoticed head movements, airspeed changes, or any vertical speed changes can cause insidious and serious glide path errors as described by Hasbrook. The "gunsight" technique is also basically a method of maintaining a constant angle of approach and does not give information regarding magnitude of approach angle. Although the utility of the "gunsight" technique for stable approaches is well established, other cues must serve for judgment of the magnitude of initial approach angles, and for judgments of approach angles during unstable approach conditions which occur because of unnoticed changes in aircraft attitude and speed, changes in head (eye) position, or due to environmental factors such as turbulence.

Size cues in the approach scene are often mentioned as important in the judgment of the glide path angle. Most theoretical presentations of size cues simply discuss the general relation of individual cues to distance and approach (glide) angle. They typically state that the pilot remembers the appropriate values of slant, size, and shape attributes of the runway which are associated with acceptable approach angles (16,28,31). During a landing approach, the pilot is thought to fly his aircraft so as to make the runway scene look "correct." The "correct" appearance is not specified by theory, however, and it is implied to vary with the individual's experiences. This conception of the process of judging approach angles is reinforced by the fact that the pilots are usually not able to tell how they identify the "correct" approach path, although they usually have confidence in their ability to do so. This undefined conception of how approach angle is judged calls attention, on an anecdotal basis, to particular cues selected during a particular landing but cannot provide a formula to a student pilot for such judgments. It also does not tell a pilot how to adapt himself to approaches at a strange airport, without prior training at that airport. Usually pilots must learn for themselves how to judge approach angles and how to generalize their

experience, based on self-assessment and/or on feedback from instructor pilots during practice approaches. In some cases, Visual Approach Slope Indicators (VASI) alongside the runway or Instrument Landing System (ILS) instruments may provide more precise feedback during learning about the relation between the visual scene viewed during the approach and the position of the aircraft with respect to the desired glide path. It would seem that a more explicit theory relating the role of various cues, including those of apparent size, shape, and slant in the runway scene, in judgments of approach angle is desirable for educational purposes. A number of potential cues involving size and shape of the runway image will be discussed in this paper regarding their relationship to approach angle. All have been said to be of use in judging approach angles.

Linear perspective is one cue involving the apparent shape of the runway image that is often mentioned as important in judging approach angle. It has been shown to determine perceived slant in laboratory experiments and it has also received theoretical attention outside the aviation literature (8,9). Linear perspective can be defined as the angle in the retinal image of the runway rectangle between the near end (threshold) of the runway and the side edge of the runway. The relationship of linear perspective in the runway image to approach angle for a particular runway size is nonlinear at a specific distance from the runway threshold and the functional relationship is different at each distance. Use of perspective to visually "measure" approach angle is, therefore, dependent on knowledge of one's distance to the runway. It is most likely that linear perspective affects judgments of approach angle through the unconscious processes that affect perceived slant. The relationship of "apparent linear perspective" to approach angle at a conscious level has not been studied but it is likely to be very complex due to the complex function relating distance and approach angle to perspective in the retinal image. Research is needed, however, to determine the importance of this cue and how it is used in approach angle judgments. Judgments of distance to the runway should also be studied in this context in relation to judgments of approach angle and apparent linear perspective.

Some have suggested that apparent height of the runway in the visual field is one cue pilots utilize (28). The angular height of the runway in the visual field is linearly related to approach angle, when measured at a particular distance, for approach angles up to 10^{o}. The function relating height to approach angle varies with distance, however, so utilization of this cue would be dependent on knowledge of runway distance, as was also the case with the linear perspective cue. In discussions of how cues such as linear perspective or image height are used, it is usually implicitly assumed that distance to the runway is perceived accurately. Pitts (27) has explicitly stated this assumption but its basis is unclear. The small amount of data which have been presented concerning judgments of distance in a simulated nighttime approach-to-landing situation show great variability and a tendency to underestimate distances (26).

It is possible, however, that some other characteristics of image shape with a more simple relation to approach angle and distance may identify the

"correct" approach angle independent of the apparent slant of the runway surface. One such cue is the angle (height) in the visual field between the aim point on the runway surface and the horizon in the visual field. If, for example, the desired aim point can be made to remain 3° below the horizon, the approach path will be a constant 3°. This cue would be independent of distance and runway size to the extent that this absolute visual angle could be judged. Langewiesche (22) has discussed this cue and considers it to be of primary importance. Its use is, however, limited to situations where the horizon is visible, and it may produce erroneous approach angles if terrain behind the runway is sloped upward (20). It would also seem to be less useful at night than in the daytime due to the difficulty of seeing the horizon and the greater potential for erroneous location of the horizon due to terrain. However, in the absence of a visible horizon at night, it is possible that the horizon position might be inferred from the apparent vanishing point of the sides of the runway. Unfortunately, so far as we know, the ability to judge the vanishing point location at night has not been studied experimentally. It is also known that judgments of the absolute size (e.g., height of the runway in the visual field) are extremely variable. On the other hand, relational size judgments are more precise than absolute judgments (12). It is possible, therefore, that if height of the runway image relative to the horizon or apparent vanishing point is an important cue, it would be judged in relation to the frame of reference provided by the cockpit windshield and the instrument panel. If so, flying an aircraft with an unfamiliar windshield size would be expected to disrupt judgments. While further study of the cue involving angular height of runway in the visual field relative to the horizon would be highly desirable, there is another potential cue involving runway shape which seems more likely to be of value in judgments of approach angle, especially at night when only runway lights are visible.

That other shape cue in the runway image has been called perspective (22, 31) and form ratio (2), and is of special interest because it has a very simple relation to approach angle, distance, runway size, and geographic slant of the runway. Because the term "perspective" is frequently used to represent the compound of all possible cues in the runway image involving absolute size, relative size, and shape (27,28), the more specific term "form ratio" will be used to refer to the cue involving ratio of height to far-end-width in the runway image. Form ratio (perspective) can be defined for the approach-to-landing situation as the ratio of height in the runway image (from near end up to the far end) relative to the width of the image of the far end as shown in Figure 1. For a particular runway, form ratio is linearly related to angle of approach (for angles up to 10°) and is independent of distance, while values of linear perspective change with distance as shown in Figure 2. The form ratio cue is also not dependent upon the visibility of terrain features, such as the horizon, or upon relations between runway image and cockpit window. The best discussion of form ratio in the aviation literature is by Langewiesche (22) who described it as the "foreshortened appearance" of the runway which varies with approach angle. Langewiesche's instruction to pilots for use of this cue went as follows:

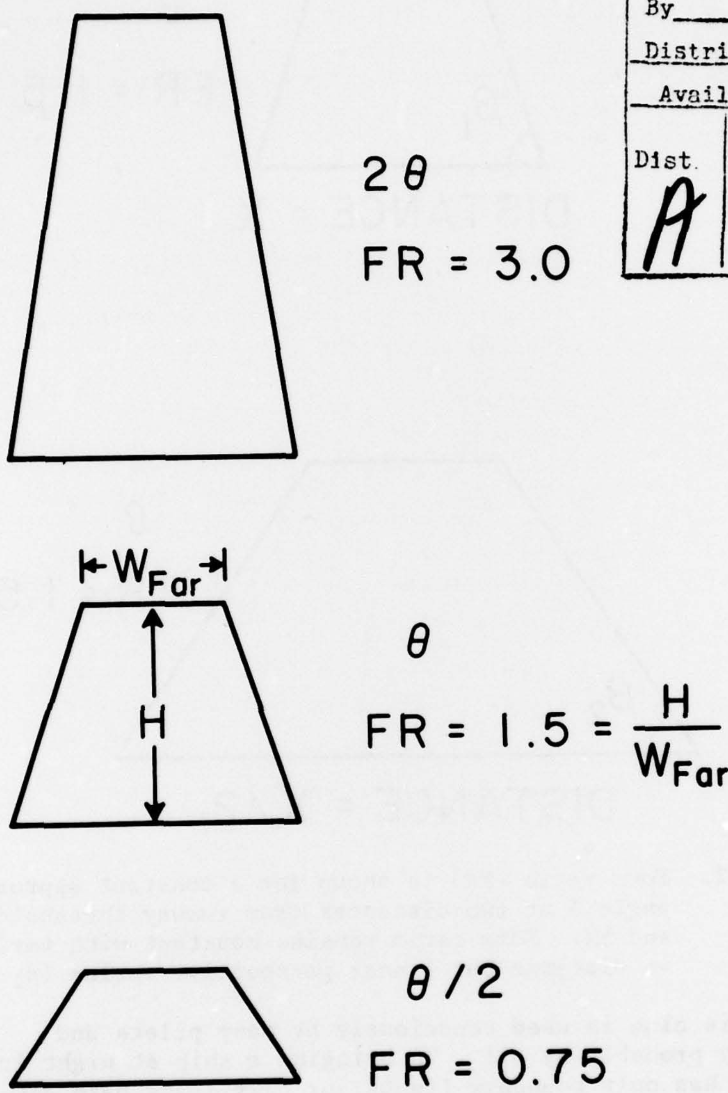

Figure 1. **Form ratio (FR) varies linearly with approach angle as shown for three approach angles, ½, 1, and 2 times angle magnitude θ. Distance is constant.**

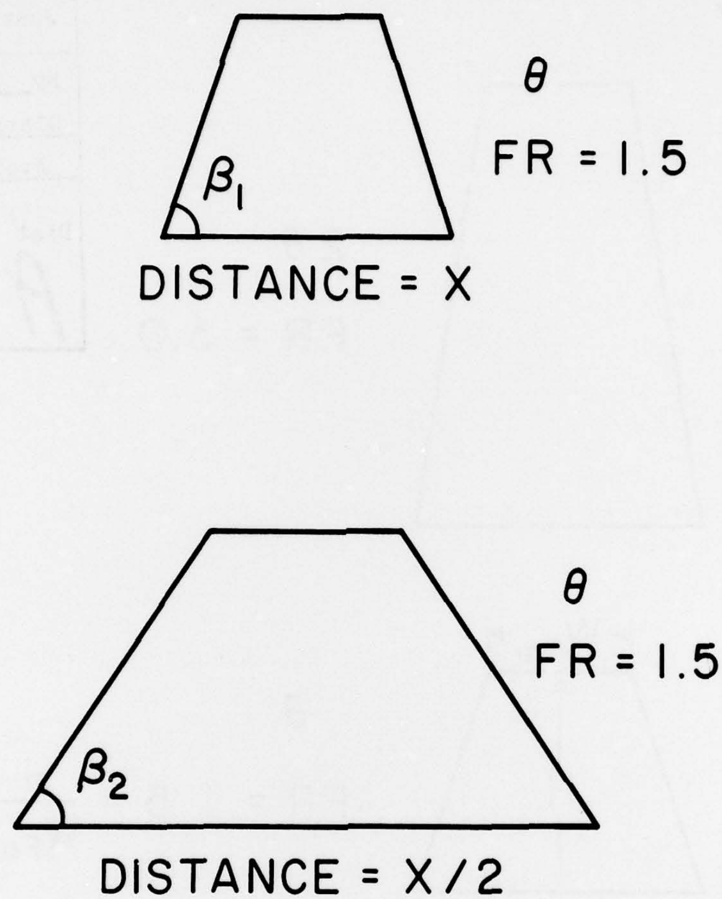

Figure 2. Form ratio (FR) is shown for a constant approach angle θ at two distances from runway threshold, X and ½X. Form ratio remains constant with variation in distance but linear perspective varies ($\beta_1 \neq \beta_2$).

". . . This clue is used consciously by many pilots and unconsciously probably by all. In bringing a ship at night into a field that has only boundary lights, or only flare path down the runway, it is sometimes the only clue, especially if the field is far away from towns or other lights and surrounded by darkness.

"For the sake of simplicity, assume that the field is square. Then, if it appears as almost square, you know that you are high over it and are thus overshooting. You know it even if you can see nothing else on the ground. If the square field appears radically foreshortened, you know that it lies

"in front" of you much more than "below" you; you are too low and probably can't reach it in a glide. If it looks "about right," you know you can probably glide into it.

"This is a fairly reliable clue. It will work from any altitude, regardless of the absolute heights and distances involved; you get the same degree of foreshortening of a square as long as you view it from the same angle; whether you view it 5 miles away and 3,500 ft up, or 0.5 mile away and 350 ft up. Thus, for one given airplane (and disregarding wind variations) there is one and only one perspective of the field that is "right;" it depends of course on the ship's gliding angle . . . . A pilot soon remembers the particular perspective that goes with his ship's particular gliding angle." (p. 262)

Although others have briefly mentioned "foreshortening" and "perspective" in the runway image as a cue (31), it has not been discussed in more depth than in the quotation above. The simple geometrical relation of form ratio to the runway variables that determine it needs to be made more explicit, therefore, and the precision with which pilots can use direct estimates of form ratio to gauge the accuracy of their approach angle needs to be assessed.

Form ratio can be calculated for a particular approach angle and runway with the equation:

$$FR = \tan\theta \left(\frac{L}{W}\right), \qquad (1)$$

where FR is form ratio, $\tan\theta$ is the tangent of the approach angle, L is the physical length of the runway, and W is the physical width of the runway. Length and width of the runway would be determined at night by the edge and end lights. This formula is a very close approximation to the exact value of form ratio and will typically not be in error more than 0.1 percent at an approach angle of 3^{o}, 0.5 percent at an approach angle of 6^{o}, or 1.5 percent at an approach angle of 10.0^{o}. These stimulus errors are very small relative to the magnitude of variability which is typical in perceptual judgments.

Form ratio could also be defined as the ratio of height to near-end width in the image of the runway. In this case, with a constant angle of approach to the runway threshold, form ratio would vary linearly with approach angle at a given distance, but would also vary with distance as would the linear perspective cue and the cue involving height of the runway in the visual field. The form ratio cue so defined would, however, remain invariant over distance with a constant angle of approach to the <u>far</u> end of the runway. On a theoretical basis, the definition of form ratio in terms of the height to <u>far</u>-end-width ratio is likely to be of greater utility since the aircraft must land near the runway threshold.

To the extent that form ratio (defined as the height to <u>far</u>-end-width ratio) might be estimated accurately, it could serve to simplify the judgment

of approach angle by making more concrete the concept of the correct approach angle's "appearance"--something that pilots are usually not able to verbalize. It might also be of special value in approaching an unfamiliar runway if the runway length, width, and geographical slant were known since the appropriate form ratio could be easily calculated in advance. However, as mentioned above, it is not known whether form ratio can be judged with sufficient accuracy to serve as a substitute for the "appearance" judgment of approach angle. There are at least two theoretical reasons for expecting errors in the perception of form ratio. These involve the fact that the observer does not have direct access to measurements of the images on his retina. The observer must rely on the perceived relative size of parts of the runway to determine perceived form ratio. Perceptual errors in estimating this ratio might be expected as the result of the perceptual phenomenon termed "shape constancy" (6,7), and the vertical-horizontal illusion (13,21). Shape constancy refers to the tendency for slanted surfaces to be perceived to have a shape which corresponds to their physical (real) shape rather than to their retinal image shape (the slanted shape on the retinal image) to the extent that cues to their true shape are present. For example, given the right cues, a slanted square which has a trapezoidal retinal image shape will still be perceived as a square. To the extent that cues about real shape are absent, perceived shape will tend to approach retinal image shape, and shape constancy is said to decrease. The monocular "depth" cues commonly thought to be important in judging approach angle are known to affect shape constancy also. Shape constancy might affect form ratio, by increasing the perceived height term in Equation 1 to the extent that observers confuse image height with apparent runway length. Projective or analytic instructions which ask the observer to ignore depth in the figure would be expected to counteract shape constancy to some extent (6).

The vertical-horizontal illusion refers to the tendency for the size of vertical objects in the visual field to be overestimated relative to the size of horizontally oriented objects of the same proximal stimulus size. The vertical-horizontal illusion would, like shape constancy, cause the height of the runway image to be overestimated relative to the horizontally oriented image of the far end. This effect would, however, be expected to be less than 10 percent (21). Form ratio might be used as a method of estimating approach angle even if systematic, but constant, errors occurred as long as variability was not too great. Compensation for constant errors in a particular observer could be accomplished by empirically measuring the perceived form ratio associated with the correct approach angle for that individual rather than using the theoretically computed value. This would be equivalent to the process mentioned by Langewiesche of an individual pilot's remembering ". . . the particular perspective that goes with his ship's particular gliding angle."

Of additional interest is the possibility that the concept of form ratio may offer a simple technique to the pilot for generalizing his experience from landings on ordinary level runways to geographically sloped runways. Form ratio for a sloped runway would be calculated by adding the slope angle

to the desired approach angle (θ in Equation 1) before the calculation. In the case of an upsloped runway, the slope to be added would have a positive value and in the case of a downsloped runway, it would have a negative value.

The geometric simplicity of form ratio and its potential for integrating information regarding approach angle, distance from the runway, variation in runway length and width, and geographical slope make it desirable to explore the ability of pilots to estimate form ratio and the range of conditions in which such judgments might be useful.

Although direct judgments of form ratio in the runway image have not been studied previously, related judgments have been studied which involved the apparent shape of specially designed runway markings. Two field studies required pilots to fly day approaches such that special markings painted on the runway appeared to have equal length and width. The markings used (diamonds, elipses, or rectangles) were designed to have equal height and width in the retinal image at specified approach angles (3,10). Both experiments found approaches flown in the daytime were similar, with and without pilot estimates of form ratio in the special runway markings--with regard both to the mean approach angles generated and to variability. Since approach angles generated without form ratio estimates were very close to the desired values, these experiments did not provide an optimal test of the utility of form ratio in correcting for constant errors. The experiment by Brown et al. did demonstrate that form ratio estimates were ineffective in increasing stability of daytime approaches over terrain which provided a rich source of visual information in addition to the form ratio target. As these authors suggested, the crucial test should occur in a situation involving reduced visual cues such as in approaches over water, desert, or at night--situations which are associated with high accident rates and visual illusions. Brown et al. also demonstrated that form ratio was overestimated in full cue approach situations in which observers were told to judge "length" of the markings relative to "width." It is possible that had pilots been instructed to judge "height" in the image (projective instructions; 4,5) relative to width, the overestimation might have been less than the 67 percent which Brown et al. reported. Zurinskas (32) observed 31 percent overestimation of form ratio in diamond runway centerline markings under simulated nighttime conditions which did not include runway edge lighting. The greater overestimation in daytime conditions would presumably be the result of greater shape constancy in a full cue situation due to greater visual information. It should be noted that, like Brown et al., Zurinskas apparently did not attempt to induce a projective set in his observers. The difference in form ratio judgments as a function of visual information does suggest that a form ratio criterion might not generalize to different situations in which the amount of size constancy would vary. However, it should be pointed out that as visual information is reduced, shape constancy should decrease and the perception of form ratio should become more accurate. It is under conditions of reduced information that help in judging approach angle is most needed. Zurinskas' (32) study had pilots and nonpilots estimate form ratio in a diamond on a simulated runway under nighttime conditions. The estimations of pilots and

nonpilots did not differ. Although Zurinskas concluded that variability between subjects observed in these estimations was too high for form ratio judgments to be useful, he did not include a control condition in which pilots made judgments of approach angle using normal nighttime cues. Therefore, the utility of form ratio in reducing either constant or variable errors cannot be decided on the basis of his data.

Two experiments are presented here to explore the ability of pilots to make direct judgments of form ratio in the runway image and to reexamine judgments of approach angle in the nighttime approach situation where only runway lights are visible, a situation often referred to as the "black hole." These experiments (i) provide further data on ability to judge approach angle at night with an unfamiliar runway and (ii) permit comparison of judgments of approach angle and form ratio with regard to identification and discrimination of simulated approach angles in the critical nighttime approach situation.

CHAPTER II

EXPERIMENT I

Introduction.

The abilities of pilots to judge (i) form ratios in the runway image and (ii) simulated approach angles were compared using a stationary runway model to simulate a wide range of approach angles and form ratios. Subjects made estimations of form ratio and category judgments of approach angle magnitude. The categories of "high," "low," and "OK" which the pilot uses many times during each approach to landing were used for these judgments of angle magnitude.

Since the task of judging form ratio required subjects to look at the scene as a picture ("projective" shape instructions) it was hypothesized that form ratio judgments might affect perceived orientation of the runway (increasing apparent slant toward a vertical orientation) and thereby affect judgments of approach angle. To evaluate this possibility, category judgments ("high," "low," and "OK") of approach angle were made together with form ratio estimates on half the trials while, during the other half, category judgments of approach angle were made together with estimates of approach angle in degrees. The latter estimates were required to induce observers to look at the runway as a slanted surface in order to assess possible effects of the "projective" set which might be carried over when prior trials involved judgments of form ratio (a sequence which occurred for half the subjects).

Method.

Subjects. Sixteen pilots (13 males, 3 females) served as subjects. Their ages ranged from 21 to 44 years and all had at least 20/20 acuity with correction, if necessary. Their flying experience ranged from 170 to 9,000 hours with a mean of 2,294 hours and a standard deviation of 2,480 hours.

Apparatus. The apparatus has been described in detail previously (24) and is shown schematically in Figure 3. The runway model (R) was the same as that used in two previous studies (25,26). The model simulated the lighting of a 170- by 6,000-ft runway with centerline, touchdown zone, and an ALSF-2 approach lighting system without sequenced strobe lights. The center of the model (F) could be moved toward the observation point (O) along an apparent path (Q) such that the center of the model was always at a constant viewing angle ($\beta=3^{o}$) below the straight-ahead direction (H) in the visual field. Two mirrors (M1 and M2) were used to produce the 3^{o} viewing angle. The slant of the model runway (θ) was varied by rotation in the vertical plane and was measured as the angle between the runway surface and the line-of-sight to the center of the touchdown zone. Absolute values of model slant were measured with accuracy to the nearest 0.1^{o}. Differences between settings of model slant were measured accurate to the nearest 0.01^{o}. The model was at a fixed simulated viewing distance of 8,000 ft from threshold. Only runway and

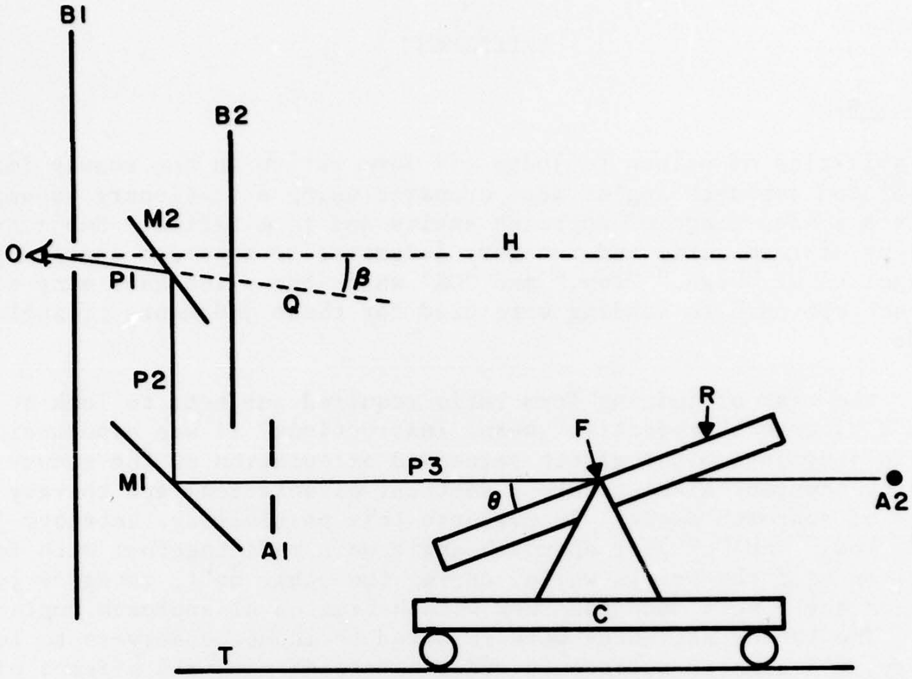

Figure 3. Schematic diagram of apparatus (A1 and A2, removable targets for aligning optical system; B1 and B2, baffles; C, cart; F, rotation axis; H, horizontal line of sight; M1 and M2, mirrors; O, eye position; P1, P2, P3, segments of the optical axis; Q, apparent axis of radial motion; R, runway model; T, track; β, viewing angle; θ, model slant).

approach lights were visible in the scene. The intensity of these lights was adjusted (and then set permanently) to appear subjectively realistic to two highly experienced commercial pilots who did not otherwise participate in the experiment. Viewing was monocular through a 12-mm aperture to eliminate binocular disparity which is not normally an effective cue during approaches to landing (27). Subjects sat in an enclosed booth during experimental observations. A chin and headrest were used to position and steady the subject's head during observations.

Experimental stimuli comprised a series of 36 values of simulated angles of approach to the center of the touchdown zone ranging from 0.25° to 9.00° in steps of 0.25°. Corresponding simulated angles of approach to threshold were from 0.3° to 10.7° at equal intervals, or steps, of 0.29°. Form ratios, the actual ratios of height to far-end width in the runway image varied from 0.18 to 6.54 in the stimulus series.

Procedure.

Responses. Subjects made three types of responses:

1. Estimations of Form Ratio. These judgments concerned the subject's perception of that aspect of runway image shape called form ratio, i.e., the ratio of height in the runway image, from threshold up to the far end, to the image width of the far end. Subjects were asked to judge the number of times the far end image width would have to be multiplied in order to make it appear equal in size to the height of the runway. Estimates were written on a response sheet by the subject at the end of each trial and subjects were told to use fractions of a ratio unit for greater precision when they felt that it was appropriate. Instructions attempted to induce "projective" or "analytic" judgments of image shape, in the language of Carlson (4,5), rather than judgments of "phenomenal" or physical shape of the runway. The projective set was induced with the following instruction: "As you look at the runway model, imagine that the field-of-view is a scene in a picture or photograph. Every image is fixed in size. If you were to cut the fixed image of the runway out, what would the ratio be of runway height to far-end width if you actually measured these dimensions in the cutout runway image?" This instruction was adapted from Epstein, Bontrager, and Park (7). For illustrative purposes, subjects were asked to make oral judgments of form ratio in two photographs of the runway model. Form ratios in those photographs were approximately 1:1 and 3:1. No feedback was given to the subject's responses either during the instruction period or during test trials.

2. Category Judgments of Approach Angle. These responses involved verbal judgments of approach angle in terms of the categories "low," "OK" (or acceptable), and "high." The acceptable or "OK" category was defined by instructions as meaning that the simulated approach angle was within the range of approach angles acceptable to insure a safe "landing." The categories "high" and "low" were defined as meaning that an altitude correction was required to get within the envelope of acceptable approach angles. During the formal experiment, category responses were written on the response sheet at the end of each trial.

3. Magnitude Estimations of Approach Angle. These responses required subjects to make estimates of the actual physical magnitude of the simulated approach angles in degrees and/or fractions of a degree as accurately as possible. Responses were written on the response sheet at the end of each trial.

Experimental Conditions. Each subject was given a total of 144 trials, two blocks of 36 trials in each of two conditions. The two conditions were the Form Ratio Condition and the Angle Condition. In each block of trials the 36 values of simulated approach angles in the stimulus series were presented once in random order. Both blocks of trials in one condition were given before the trials of the next condition were begun. The three kinds of responses described above were administered in the two experimental conditions

as follows: In the Form Ratio Condition, subjects judged whether the simulated approach angle appeared to be "high," "low," or "OK" and also judged the (form) ratio of height to far-end width in the runway image on each trial. In the Angle Condition, subjects again made category judgments of approach angle, but then estimated magnitude of the simulated approach angle instead of the form ratio. The order in which these two conditions was presented was counterbalanced over subjects. Subjects were given a 5-min break between the two blocks of trials in each condition and a 10-min break between conditions. Before test trials were begun in each condition, 15 practice trials were given with stimuli randomly selected from the stimulus series for each subject.

A brief tone alerted the subject at the start of each trial and the dim overhead light in the booth went out. Two seconds later the lights of the runway model came on and were visible for 10 seconds during which the subject judged whether the simulated approach angle was "high," "low," or "OK" and then estimated either form ratio in the runway image or the magnitude of the simulated approach angle in degrees. When the lights of the model went out after 10 seconds, the booth light came on and the subject had 20 seconds to write down his/her responses. During the 20-s response period between trials, the simulated approach angle was changed by the experimenter in preparation for the next trial. A white noise was presented for the entire 20-s response period to mask the noise of the motor used to control simulated approach angle. Approximately 2 seconds after the noise ceased, the next trial was begun. Each block of 36 trials took approximately 18 min and the entire experimental session lasted about 2 h.

Results.

Form Ratio Estimations. The relation of judged (perceived) form ratios to stimulus (actual) form ratios that occurred as a function of varying simulated approach angles is shown in Figure 4. The mean, the median, and the range of responses to each stimulus value are shown. The dashed line represents the function that would be obtained if perceived ratios were identical to actual ratios. Means and medians of responses are in close agreement and indicate overestimation of stimulus form ratio throughout the stimulus range. The amount of overestimation decreases relative to the stimulus value over the range of stimuli presented. Variability in the range of responses (Figure 4) increases with stimulus magnitude. The high and low values plotted in Figure 4 represent the highest and lowest estimations produced by any subject at each stimulus value and, therefore, confound intrasubject and intersubject sources of variability. These two kinds of variability are shown separately in Figure 5. Intrasubject variability in responses to each stimulus was measured by determining for a particular subject the difference between the two responses to each stimulus. The root mean square difference for the 16 subjects was then calculated for each stimulus value and is shown in Figure 5. Intersubject variability was measured by averaging the two form ratio responses of each subject to each stimulus and calculating the standard deviation of these values over the 16 subjects.

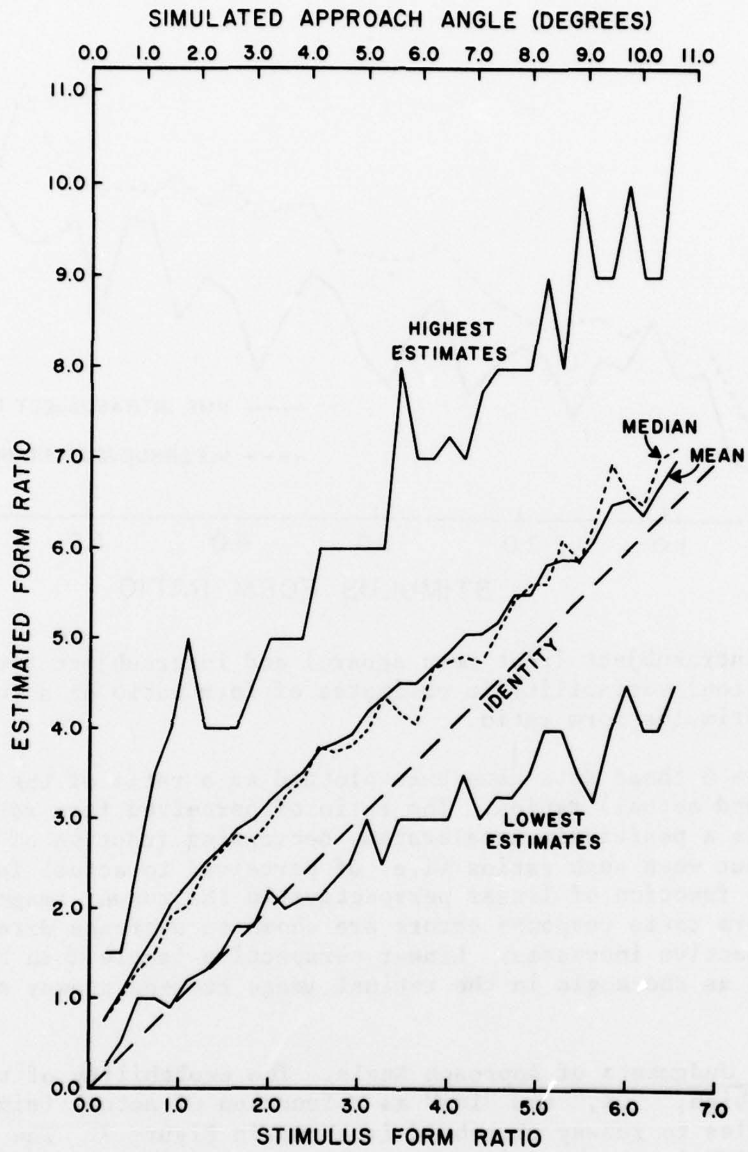

Figure 4. Estimates of form ratio as a function of stimulus form ratio.

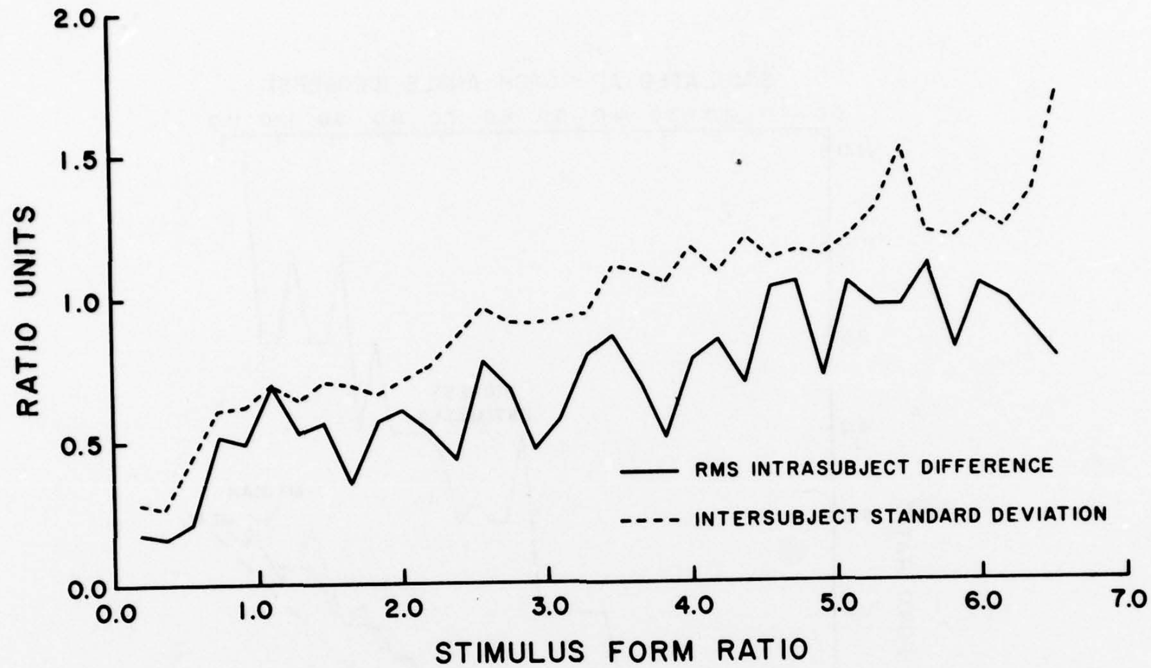

Figure 5. Intrasubject (root mean square) and intersubject (standard deviation) variability in estimates of form ratio as a function of stimulus form ratio.

In Figure 6 these data have been plotted as a ratio of the two (perceived and actual) ratios. The ratio of perceived form ratio to actual form ratio is a positively accelerated, decreasing function of stimulus magnitude, but when such ratios (i.e. of perceived to actual form ratio) are plotted as a function of linear perspective in the runway image, as in Figure 6, form ratio response errors are shown to decrease directly as linear perspective increases. Linear perspective (angle β in Figure 2) is defined here as the angle in the retinal image between runway edge and near end lights.

<u>Category Judgments of Approach Angle</u>. The probability of responses in the categories "high," "OK," and "low" as a function of actual (simulated) approach angles to runway threshold is shown in Figure 7. The threshold ($p=.5$) for "OK" in the group's responses was at a simulated approach angle of 1.65° and the threshold for "high" was at 5.0°. "OK" was the most frequently occurring response to simulated approach angles between those values. Note also that "OK" responses occurred with simulated approach angles as low as 0.9° and as high as 10.4°. "Low" responses occurred at simulated approach angles as high as 5.35° and "high" responses occurred at simulated approach angles as low as 2.1°. Although such category judgments are thought to be

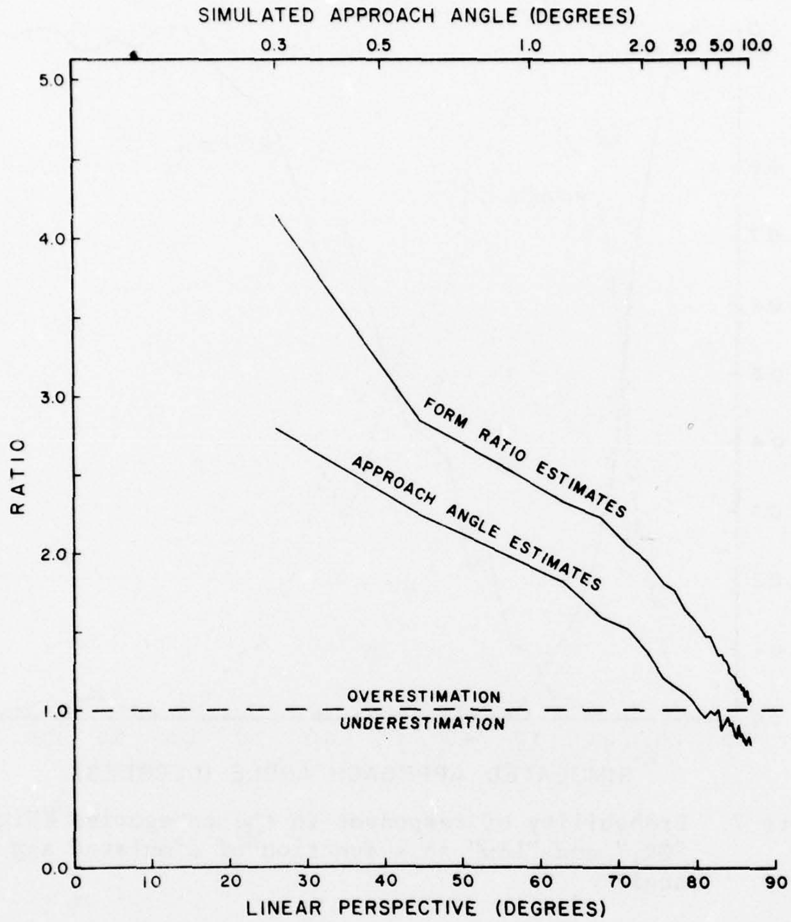

Figure 6. Ratio of both estimated form ratio to stimulus form ratio and estimated approach angle in degrees to simulated approach angle as a function of linear perspective in the runway image.

"natural" to pilots, considerable variability is manifest. The mean stimulus value judged "OK" was 3.4°; the median was 2.85°. This reflects the positive skew of the distribution of the "OK" category.

Comparison of Form Ratio and Approach Angle Responses. Comparisons can be made of form ratio estimates and category judgments of simulated approach angle by using a method operationally similar to the method of successive categories (14,23). In this method data are plotted in terms of the probability of response as a function of stimulus magnitude. Probability in this context refers to the relative frequency of a category ("low," "OK," or "high"), or a numeral in the case of form ratio estimates, equal to or greater

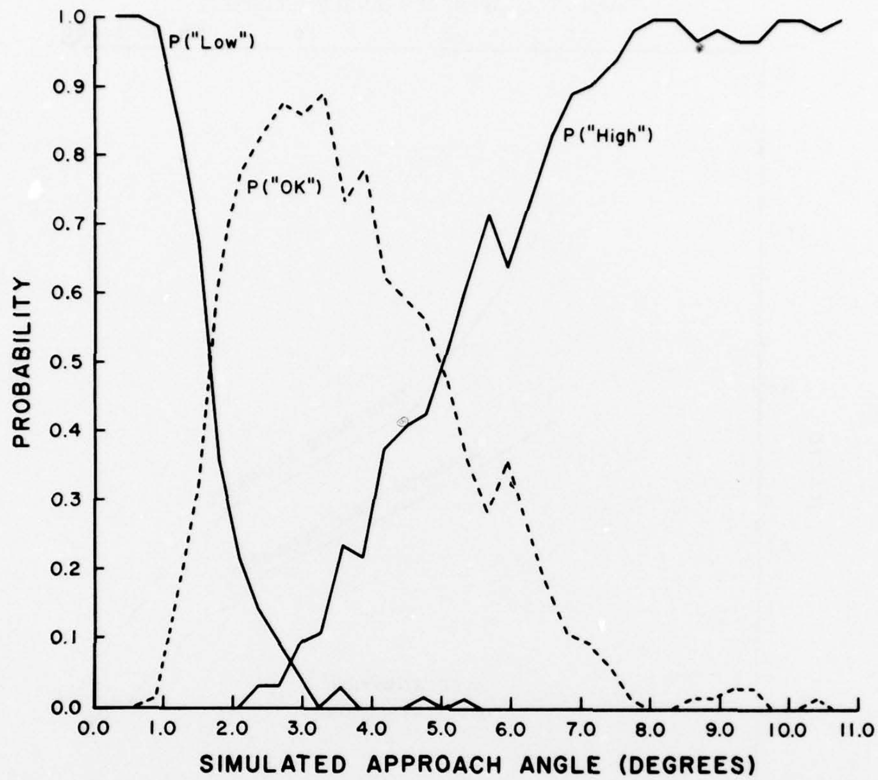

Figure 7. Probability of responses in the categories "High," "OK," and "Low" as a function of simulated approach angle.

than a certain value. It should be noted that this method is usually applied to determine response thresholds and response variability in the data of an individual observer in a psychophysical experiment; in the present application, group performance is measured by combining responses of all subjects and treating them in the same manner as data from a single subject. Indices of thresholds and variability resulting from this analysis, therefore, refer to group performance. In the resulting psychometric functions, "threshold" for a response category is P(R)=0.5. The slope of the function or the rate at which the probability of a response increases with stimulus magnitude is a measure of stimulus discrimination. The more rapidly the probability of a response increases as a function of an increase in stimulus magnitude, the more acute discrimination is. These psychometric functions are shown for category judgments of approach angle and estimates of form ratio in Figures 8 and 9, respectively. In general psychometric functions for response categories of greater magnitude show a shallower slope. That is, in these subjects as response magnitude increases, the discriminability of stimuli decreases. The difference between stimulus values associated with response

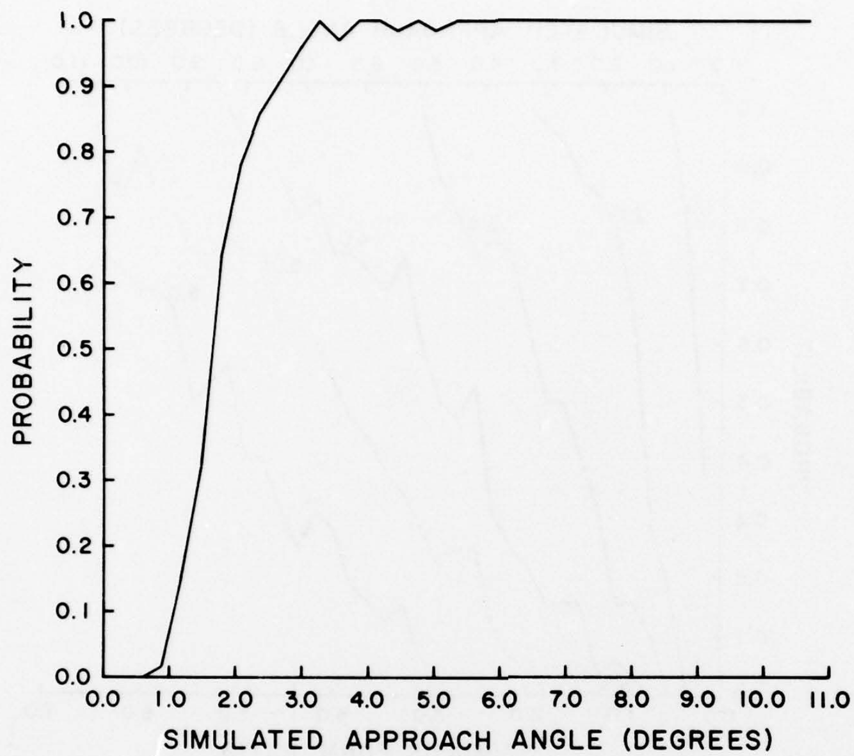

Figure 8. Probability of a category response equal to or greater than "OK" as a function of simulated approach angle.

probabilities of 0.25 and 0.75, or the interquartile range in each of the psychometric functions in these figures, can be obtained as a measure of discriminability. The psychometric functions for "high" responses and "OK" responses are shown in Figures 7 and 8, respectively. Psychometric functions for form ratio responses 1.0 through 6.0 are shown in Figure 9. Thresholds and corresponding interquartile ranges were derived from the above functions for the categories "OK" and "high" and the form ratio responses 2.0, 3.0, 4.0, and 5.0. Interquartile range is plotted as a function of threshold for both category and form ratio judgments in Figure 10. These graphs show that, for a given threshold value, the lowest interquartile range values were obtained with category judgments of approach angle; range values for form ratio estimates were slightly but consistently higher. Category judgments of approach angle were, therefore, slightly less variable than estimates of form ratio. With both types of responses, the interquartile range increases as a function of the stimulus magnitude at response threshold.

Magnitude Estimations of Approach Angle. The relation of estimates of approach angle in degrees to actual (simulated) approach angle is shown in

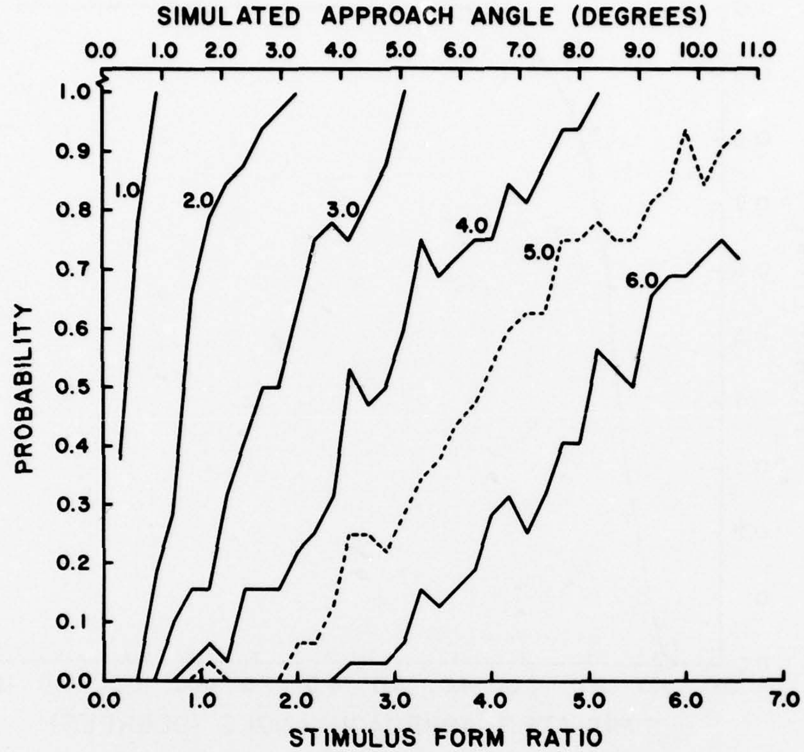

Figure 9. Probability of a form ratio response equal to or greater than numerical values from 1 to 6 as a function of simulated approach angle.

Figure 11. Both the mean and median of estimated approach angles are plotted as a function of actual approach angle along with the extreme responses (highest and lowest) that occurred at each stimulus magnitude. Although the means and medians are in fairly close agreement at lower values of simulated approach angle, the distributions of responses to each stimulus tended to be positively skewed, with means becoming increasingly greater than median responses as stimulus magnitude increased. Both measures indicate lowest errors in the vicinity of the 3^{o} actual approach angle, overestimation at values less than 3^{o}, and underestimation of the actual approach angle at stimulus values greater than approximately 3.5^{o}. It should be noted in Figure 11 that actual approach angles as low as 0.9^{o} and as high as 10^{o} produced a response of 3^{o}. Although constant errors are least at a stimulus value of 3^{o}, the range of estimated approach angles does not seem to be less at this stimulus value.

Indices of intrasubject and intersubject variability in estimates of approach angles were calculated in the same manner as in the case of form

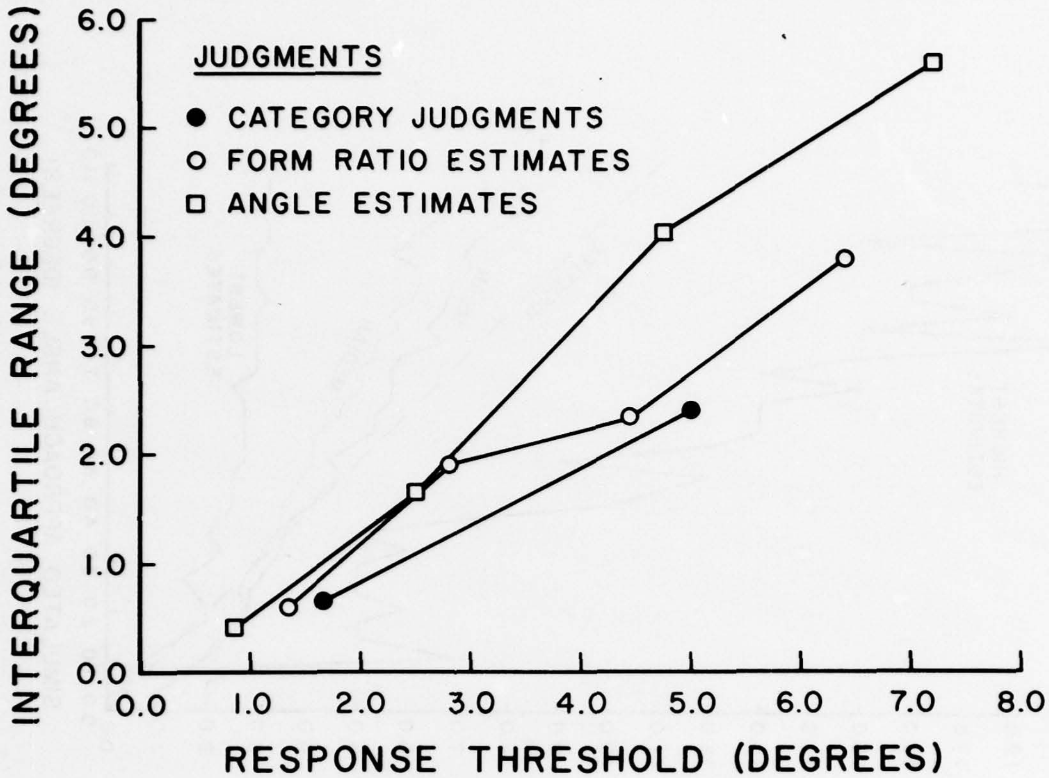

Figure 10. Interquartile range in degrees as a function of response threshold magnitude for category judgments of approach angle, form ratio estimates, and approach angle estimates.

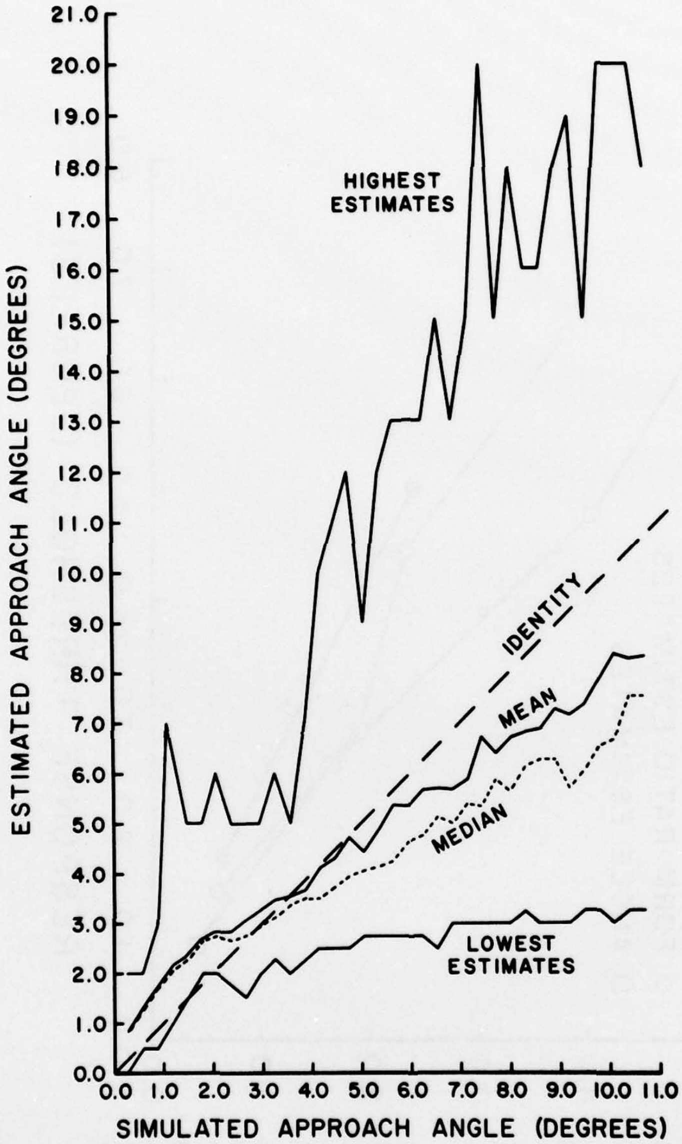

Figure 11. Estimates of approach angle in degrees as a function of simulated approach angle.

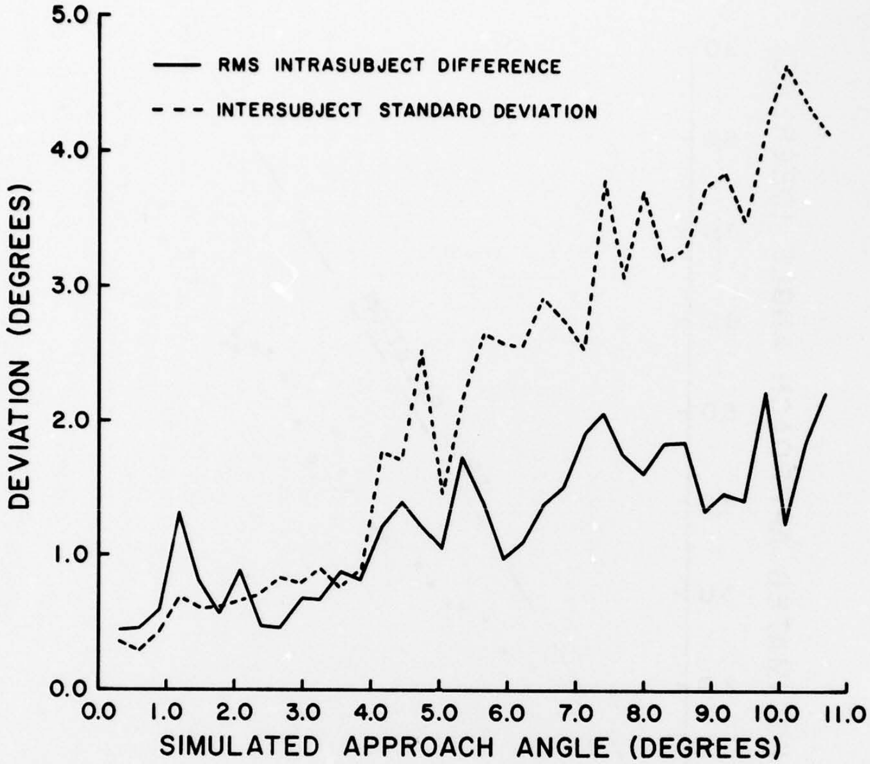

Figure 12. Intrasubject (root mean square) and intersubject (standard deviation) variability in estimates of approach angle in degrees as a function of simulated approach angle.

ratio estimates. Intrasubject and intersubject variability of responses generally increases with magnitude of stimuli as shown in Figure 12. Features of interest in these curves are the suggestion of a local minimum in the curve for intrasubject variability between 2° and 3° actual approach angles, and the increase in slope of the intersubject variability function at about 4°. The positive identification of these features is complicated, however, by the irregularity apparent in all parts of these curves.

Probability of response functions similar to those provided earlier for form ratio estimations were prepared for approach angle estimations but are not presented here for sake of brevity since angle estimations are not of primary interest. In general, the discrimination of stimuli evident in angle estimates was less than with either category judgments of approach angles or form ratio estimation as shown by interquartile ranges of psychometric functions in Figure 10.

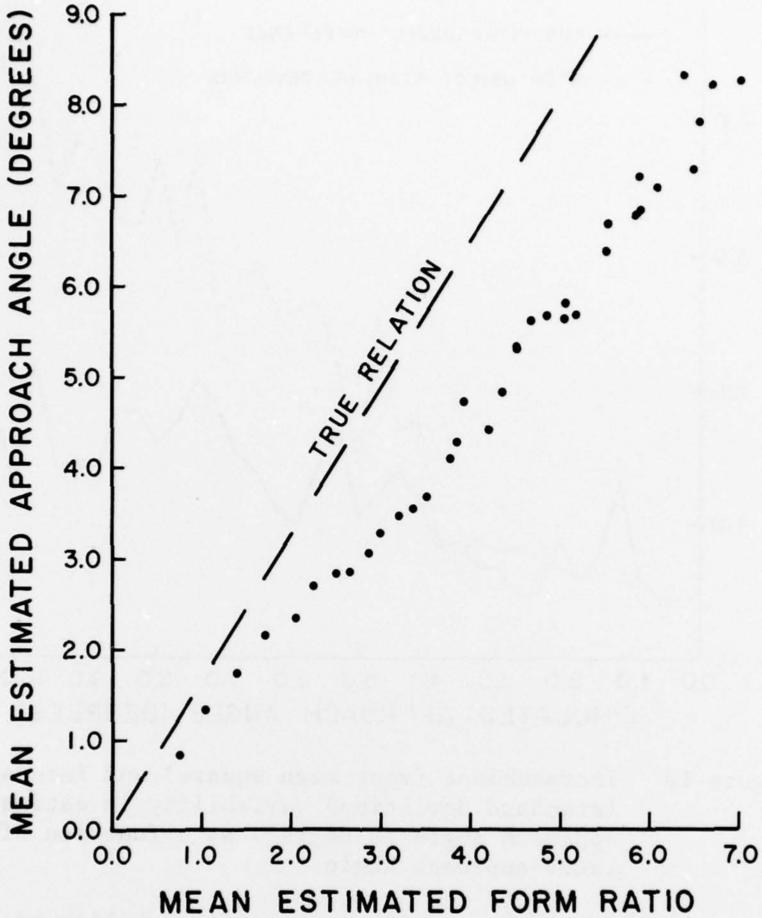

Figure 13. Estimates of approach angle in degrees as a function of estimated form ratio.

The relation of estimates of approach angle in degrees to estimates of form ratio is shown in Figure 13. For each value of simulated approach angle, mean estimated approach angle is plotted as a function of mean estimated form ratio. The true relation of approach angle to form ratio is shown by the dashed line. The observed relation of estimated approach angle to estimated form ratio was approximately linear, but falls below the true relation. Variability in the relation increases with response magnitude.

Effect of Form Ratio Estimations on Category Judgments of Approach Angle. The question of whether the "projective" set for the form ratio estimations would cause category judgments of approach angle to occur at lower actual angles of approach than in the angle estimation condition was tested by comparing stimulus values of actual approach angles which were judged "OK" in

the two conditions. Calculations were made of the mean, the median, the low, and the range of actual approach angles judged "acceptable" by each subject in each of the two conditions. The average of each of these statistics is shown for both experimental conditions in Table 1.

TABLE 1. The Averages in Degrees of the Mean, Median, Low, and Range of Simulated Approach Angles Judged "OK" by an Individual Subject on Both Approach Angle Estimation and Form Ratio Estimation Trials

Statistic	Angle Estimation Trials	Form Ratio Estimation Trials	Difference
Mean	3.56	3.43	0.13
Median	3.49	3.36	0.13
Low	1.56	1.66	-0.10
Range	4.58	4.17	0.41

The mean actual approach angle judged "OK" averaged 0.13° higher in the Angle Condition than in the Form Ratio Condition. This difference was not statistically significant, nor were the median, lowest value, or range of stimuli judged "OK" significantly different in the two conditions as determined by independent t tests. The 0.13° difference in stimuli judged "OK" in the two conditions is extremely small relative to the mean range of stimuli judged acceptable by individual subjects and is on the order of magnitude of error inherent in the apparatus for measuring simulated approach angle (0.1°). Estimations of form ratio, therefore, had no effect on category judgments of approach angle made on the same trials.

Discussion.

The present experiment did not provide feedback to pilots concerning the accuracy of their responses. The approach angle judgments in the present study were analogous, therefore, to judgments of an unfamiliar runway as would be the case the first time a pilot landed at a strange airport. The most important finding was that such judgments of approach angle were extremely variable. Simulated approach angles from 0.9° to 10.0° elicited at least one "OK" response in the group of subjects and the average range of angles judged "OK" by an individual was greater than 4°. These findings suggest that ability to judge approach angle is limited when the only cues available are size cues and shape cues in the runway image. This finding of great variability both between subjects and within the performance of an

individual indicates the need for further study of the generalization of visual experience from one approach-to-landing situation to unfamiliar runway situations, especially when the unfamiliar runway involves the nighttime "black hole" situation.

Estimations of form ratio as well as category judgments of approach angle exhibited considerable variability, both within the responses of an individual and between subjects. Category judgments showed slightly less variability and, consequently, somewhat more precise discrimination of approach angles than did form ratio estimations, as indicated by a comparison of these two types of judgments in terms of interquartile range in the psychometric functions relating probability of response greater than or equal to particular values. This finding does not support the utility of estimates of form ratio as a supplement for judgments of approach angle, in agreement with the findings of Brown et al. (3) as previously discussed. It should be noted, however, that observers in the present study had no prescribed training in estimating form ratios. Such training might reduce both intrasubject and intersubject variability. While intersubject variability might be reduced by training, it could also be compensated for by utilizing knowledge of idiosyncracies in psychophysical functions relating perceived form ratios to actual approach angles. Separately determining for each subject the form ratio value associated with the desired approach angle for a particular runway is such a compensation technique and it is identical to the procedure which Langewiesche (22) and Wulfeck et al. (31) described for adjustment to a new runway. Although the present data do not support the utility of form ratio estimates as a supplement to approach angle judgments, they do demonstrate that estimates of form ratio do not affect judgments of approach angle made at the same time. It is important that this be the case if form ratio estimates are to have any value. Category judgments of approach angle in terms of "high," "OK," or "low," the conventional pilot's judgment would, therefore, be available as a check on approach angle judgments based on form ratio estimates.

Overestimation of both perceived form ratio and approach angle (in degrees) was a linear function of linear perspective in the runway image such that overestimation increased as simulated approach angle decreased. As the above relations require, estimated approach angle was a linear function of estimated form ratio. Although this does not imply a causal relation between these attributes, it does indicate that possibility and that they are a function of similar variables. Linear perspective in particular is indicated as an important cue in the determination of both responses. The possibility that form ratio is used unconsciously as a cue for judgment of approach was not at issue in the present experiment, but future research should attempt to determine the importance of both stimulus form ratio in the runway image and apparent form ratio as determinants of approach angle judgments. The present findings indicate that direct estimates of form ratio cannot supplement judgments of approach angle, but if apparent form ratio is a cue for judging approach angle, variability in approach angle judgments may be "explained" as due to variability in perception of form ratio.

From the data shown in Figure 11, it would be predicted that, if pilots were asked to produce a 3^{o} approach angle, their average response would result in a 2.6^{o} approach angle to threshold. This contrasts with data of a previous experiment (26) involving a task in which pilots attempted to adjust the model runway to produce a 3^{o} approach angle. In that earlier experiment, a simulated approach angle of 1.5^{o} measured to the center of the touchdown zone, was judged to be 3^{o} on the average. That corresponds to an angle to threshold of approximately 1.7^{o} which is substantially less than the above prediction based on present data. Thus, the following experiment reexamines responses of pilots in a dynamic task requiring them to produce a 3^{o} approach angle.

CHAPTER III

EXPERIMENT II

Introduction.

The previous experiment examined constant and variable errors in estimations of form ratio and category judgments of approach angle at one simulated distance from runway threshold. This present experiment was designed primarily to investigate how those functions would vary with distance from threshold. It also sought to compare verbal estimation responses in the static (stationary) condition with "production" responses made under more realistic dynamic conditions in which the model was moving and observers controlled the slant of the model (i) to produce particular values of form ratio (1.0, 2.0, and 3.0), or (ii) to produce a 3^{o} approach angle. For a runway with the dimensions of the present model, the form ratio of 2.0, if produced accurately, would give a generated approach angle of 3.24^{o}. Performance in 3^{o} approach angle and 2.0 form ratio production tasks were compared regarding constant and variable errors.

Estimates of approach angle in degrees obtained in Experiment I would predict that, if asked to produce a 3^{o} approach angle, pilots would actually produce a 2.6^{o} simulated approach angle on the average. As mentioned above, that prediction conflicts with findings of a previous study (26) in which pilots produced a simulated approach angle to threshold of approximately 1.7^{o} when instructed to produce a 3^{o} approach angle. This difference might be attributed to the fact that pilots in that earlier experiment had participated in another task prior to trials on which they adjusted the model to produce a 3^{o} approach angle. That earlier study (26) involved adjusting the model runway to appear horizontal, i.e., parallel to the ground. The model appeared horizontal, on the average, at a simulated approach angle of approximately 1^{o} and pilots typically never saw the model at a simulated approach angle higher than 3^{o}. It is possible that prior exposure to a small range of low simulated approach angles affected the criterion of pilots in the subsequent trials of the 3^{o} production task in that previous study (26). A possible mechanism for such an effect is suggested by adaptation level theory (18). The perceptual magnitude of any stimulus, e.g., a particular angle of approach, is determined by its relation to the adaptation level, which is a weighted average of all previous stimuli experienced. Viewing low approach angles would lower adaptation level. If the criterion for a desirable approach angle was near the adaptation level, responses in the 3^{o} production task would be lowered following the horizontal adjustment trials in the earlier experiment. To test this possibility, half the subjects of the present experiment made 3^{o} production responses without prior performance of any task and the other half made 3^{o} production responses following trials on which form ratio was estimated over a wide range of simulated approach angles. It was predicted that, when 3^{o} production responses were obtained first, the average generated approach angle would be (i) greater than that observed in the previous experiment but (ii) less than in the condition in

which the model was seen over a wide range of simulated approach angles as high as 7° prior to the 3° production task.

Method.

Subjects. Twenty male pilots served as subjects. Their ages ranged from 26 to 58 years and all had at least 20/20 acuity with correction, if necessary. Their flying experience ranged from 305 to 10,000 hours with a mean of 2,774 hours and a standard deviation of 2,177 hours. All pilots had an instrument rating.

Apparatus. The model and apparatus were identical to that used in Experiment I.

Procedure

Static Trials. On all static trials, subjects again made category judgments of actual approach angles to the model runway and estimated form ratios. Estimations of approach angle in degrees were not made at any time during static trials of this experiment. The procedure for static trials was identical to that in Experiment I with the exceptions that observations were made at two simulated distances from threshold, 8,000 ft and 26,000 ft, and an abbreviated set of approach angles was used.

At both 8,000 ft and 26,000 ft simulated distances, approach angles to the middle of the touchdown zone varied from 0.5° to 6.0° in steps of 0.5°. At the near distance this corresponded to 12 approach angles to threshold from 0.59° to 7.12° in equal steps of 0.594°. Actual form ratios in the stimulus series for the near distance ranged from 0.37 to 4.38. At the far distance the corresponding approach angles to threshold ranged from 0.53° to 6.35° in equal steps of 0.529°. Actual form ratios in the stimulus series for the far distance ranged from 0.33 to 3.90. Simulated distance was varied in five blocks of trials in two orders, AABBA and BBAAB. Order of distance presentation was counterbalanced by randomly assigning each of the two orders to half the subjects. Each block of trials consisted of 12 trials in which each of the 12 approach angles appropriate for the particular distance was presented once in random order. The first block of trials was for practice purposes and these data were not analyzed.

Dynamic Trials. On dynamic trials, the subject controlled the angle of approach to make the form ratio of the model runway appear to be either 1.0, 2.0, or 3.0, i.e., to make the apparent height in the image either equal to, 2 times, or 3 times the apparent width of the image of the far end of the runway. Instructions used the same definition of form ratio given in Experiment I. Each ratio was produced three times, each time with the model at a different slant at the start of the trial. The starting angles used with each ratio criterion were -1.0°, 0.0°, and 1.0° from the simulated approach angle producing the stimulus form ratio specified by the response criterion. Two practice trials preceded test trials in the dynamic condition.

The nine combinations of three starting slants and three ratio criteria were presented in random order.

3° Approach Angle Production Task. Subjects were given six trials on which they were asked to control the model ". . . in order to make the runway look like a runway does on a 3° glide path during an approach to landing." On 3° criterion trials, two starting approach angles were used, 0.5° and 3.0°, in order to make this condition comparable to that of an earlier study (26). It should be noted that, in the dynamic condition of that earlier study (26), there was no significant effect of starting angle on the 3° Production task when the same psychophysical method used in the present experiment was involved. Starting angle was counterbalanced over subjects by assigning each of the orders ABBAAB and BAABBA to half the subjects. The first two trials were practice and those data were not used in the analysis.

The three types of trials were presented in two orders: The first order presented to half the subjects was (i) 3° Production, (ii) Form Ratio Production, and (iii) Static Trials. The other order was (i) Static Trials, (ii) Form Ratio Production, and (iii) 3° Production. On dynamic trials in both the Form Ratio Production and the 3° Production conditions, the model was always visible as it approached over the range of simulated distances from 26,000 ft to 8,000 ft from threshold. The simulated approach speed in all dynamic trials was 125 knots. The subject controlled either the apparent approach angle or apparent form ratio by a modified method of adjustment. The model was constantly rotating in the vertical plane as it approached the subject during experimental trials. The subject's task was to control the direction of rotation either to make the model look like a runway does on a 3° approach or to produce a particular form ratio on the runway image. Each time the model appeared to be rotating away from the desired response criterion the subject was instructed to reverse the direction of rotation to make the model rotate back toward the orientation at which it appeared to match the perceptual criterion. During adjustments in both static and dynamic conditions, the model rotated in the vertical plane at a rate of 10°/minute.

Results.

Static Condition. The relation of perceived form ratio to actual form ratio at the simulated distances of 8,000 ft and 26,000 ft from runway threshold is shown in Figures 14 and 15, respectively. The functions relating mean and median responses to actual form ratio are in close agreement as in the data of Experiment I. Overestimation is slightly less, however, over the entire range of stimulus values at the farther simulated distance. Intersubject variability measured in terms of the standard deviation of individual means is shown as a function of actual (stimulus) form ratio for both simulated distances in Figure 16. Intersubject variability was only slightly higher at the near distance. Intrasubject variability, shown in Figure 17, was measured in terms of the root mean square difference between the two

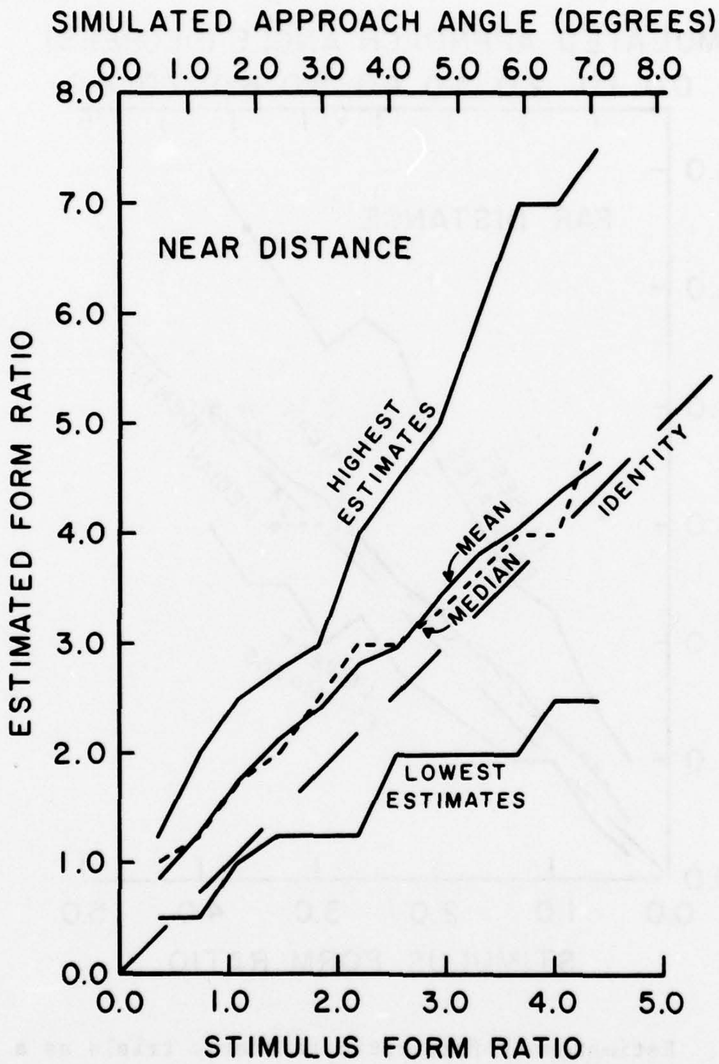

Figure 14. Estimates of form ratio in static trials as a function of stimulus form ratio at the near (8,000 ft) distance.

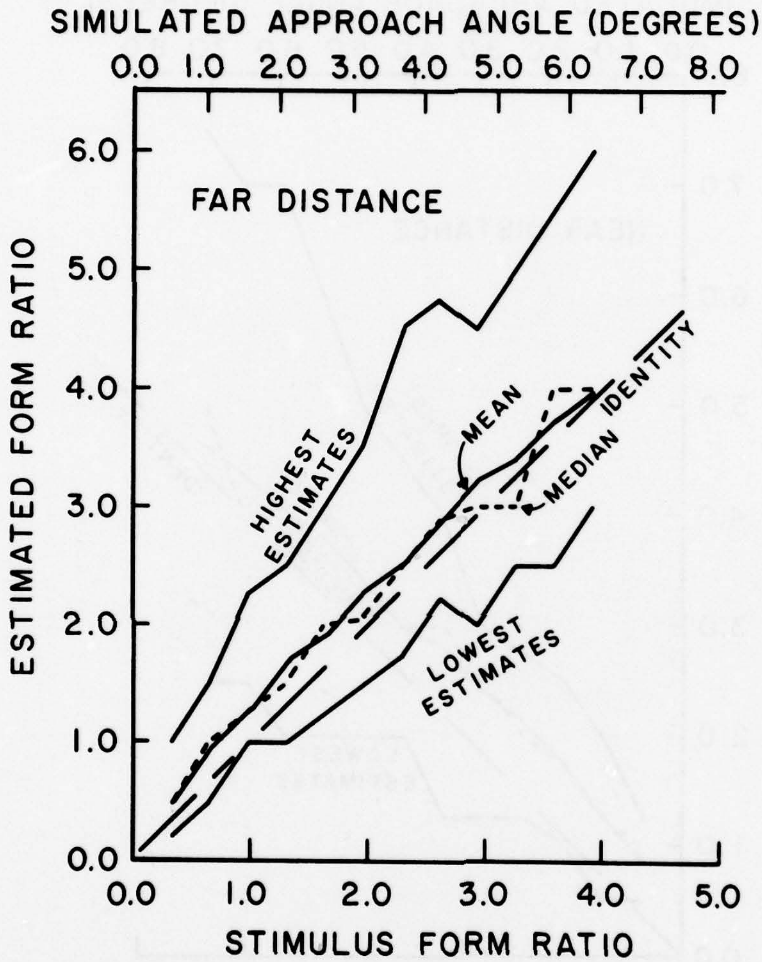

Figure 15. **Estimates of form ratio in static trials as a function of stimulus form ratio at the far (26,000 ft) simulated distance.**

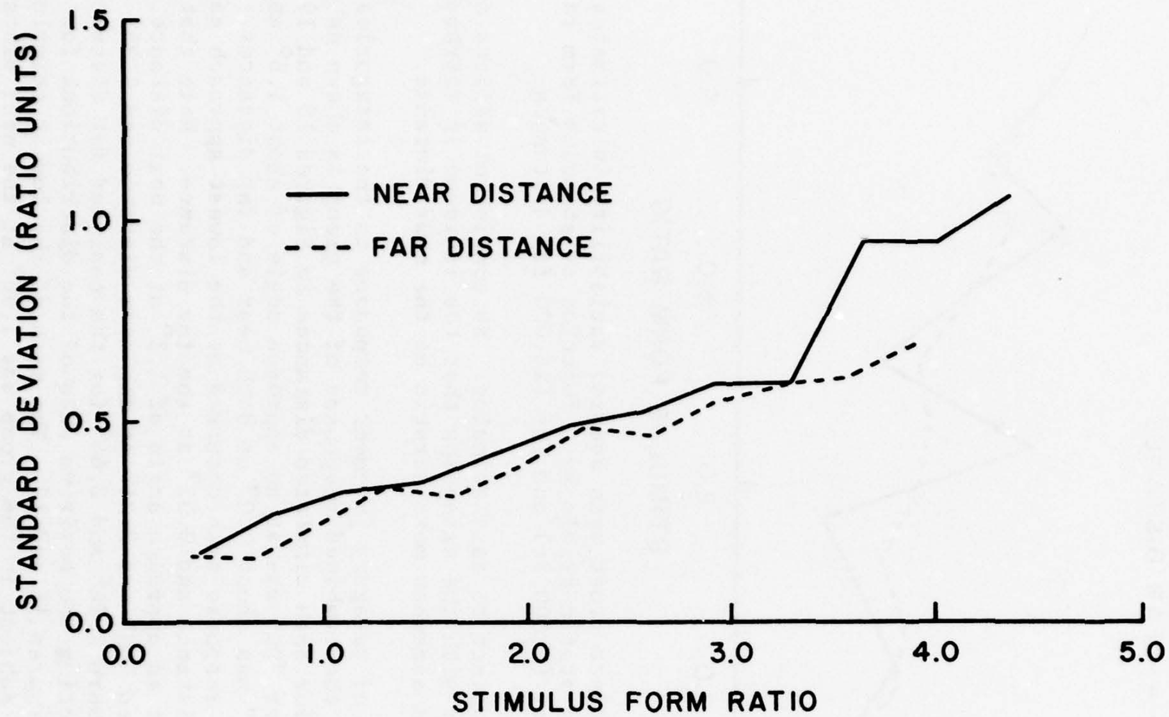

Figure 16. Intersubject (standard deviation) variability in estimates of form ratio in static trials as a function of stimulus form ratio at both near (8,000 ft) and far (26,000 ft) distances.

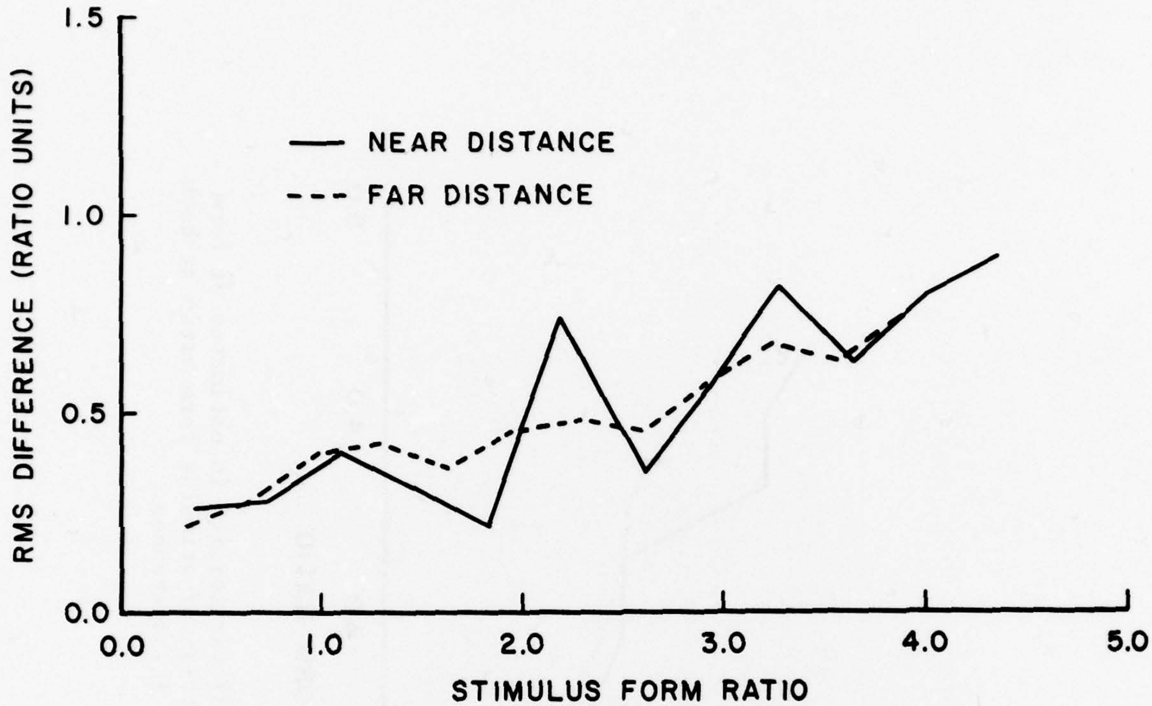

Figure 17. Intrasubject (root mean square) variability in estimates of form ratio in static trials as a function of stimulus form ratio at both near (8,000 ft) and far (26,000 ft) distances.

responses by each subject to each stimulus. No consistent effects of distance are notable with the exception that the increase in intrasubject with actual form ratio is somewhat more erratic at the near distance.

The probability of category judgment responses in the categories "high," "low," and "OK" for the combined responses of the group is shown as a function of approach angles for both simulated distances in Figures 18 and 19. The threshold ($p=0.5$) for "OK" was at an approach angle of about 1.8° and the threshold for "high" was about 4.0° at both near and far distances. At both distances, one "OK" response each occurred at the lowest approach angle, 0.59° at the near distance and 0.52° at the far distance. Note that a "high" response occurred at an approach angle of 1.2° at the near distance. The mean approach angle judged "OK" was 3.21° at the near distance and 2.95° at the far distance. Medians were 2.94° and 2.64° for the near and far distances, respectively, reflecting the positive skew of the distributions for the "OK" category shown in Figures 18 and 19. The mean of the lowest stimulus value judged "OK" by each subject in the group was 1.96° at the near distance and 1.80° at the far distance.

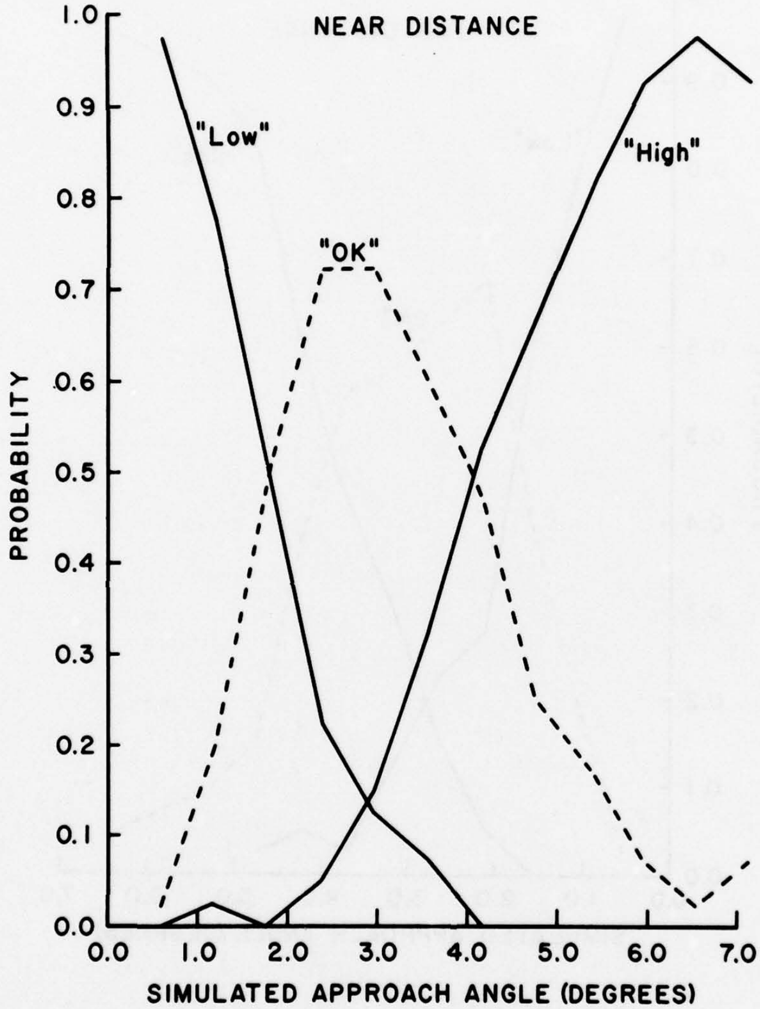

Figure 18. Probability of response in the categories "High," "OK," and "Low" as a function of simulated approach angle at the near (8,000 ft) distance.

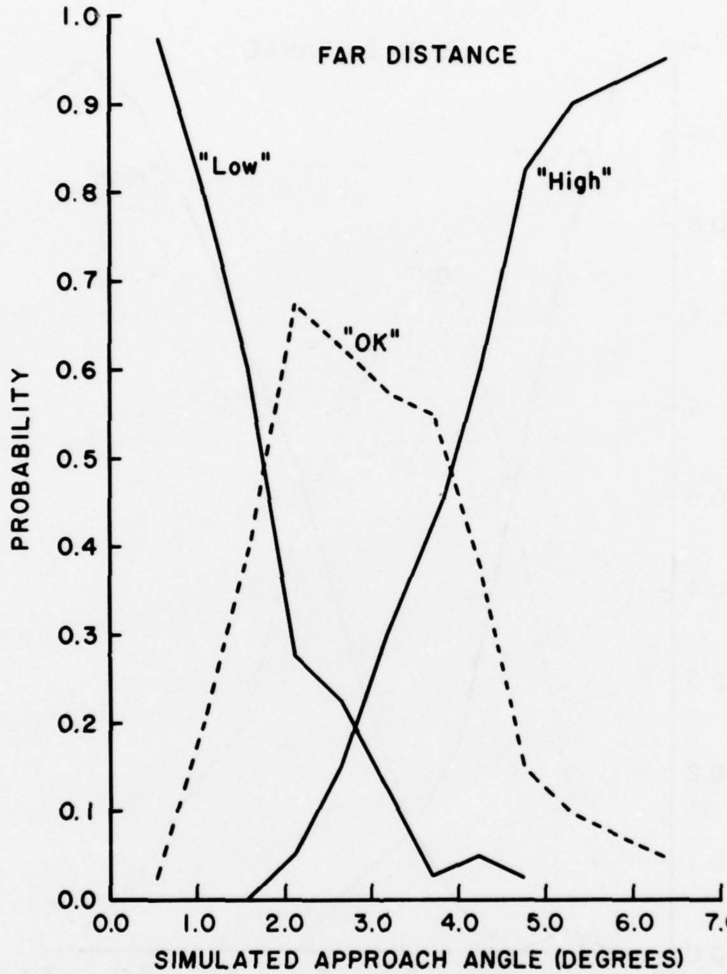

Figure 19. Probability of response in the categories "High," "OK," and "low" as a function of simulated approach angle at the far (26,000 ft) distance.

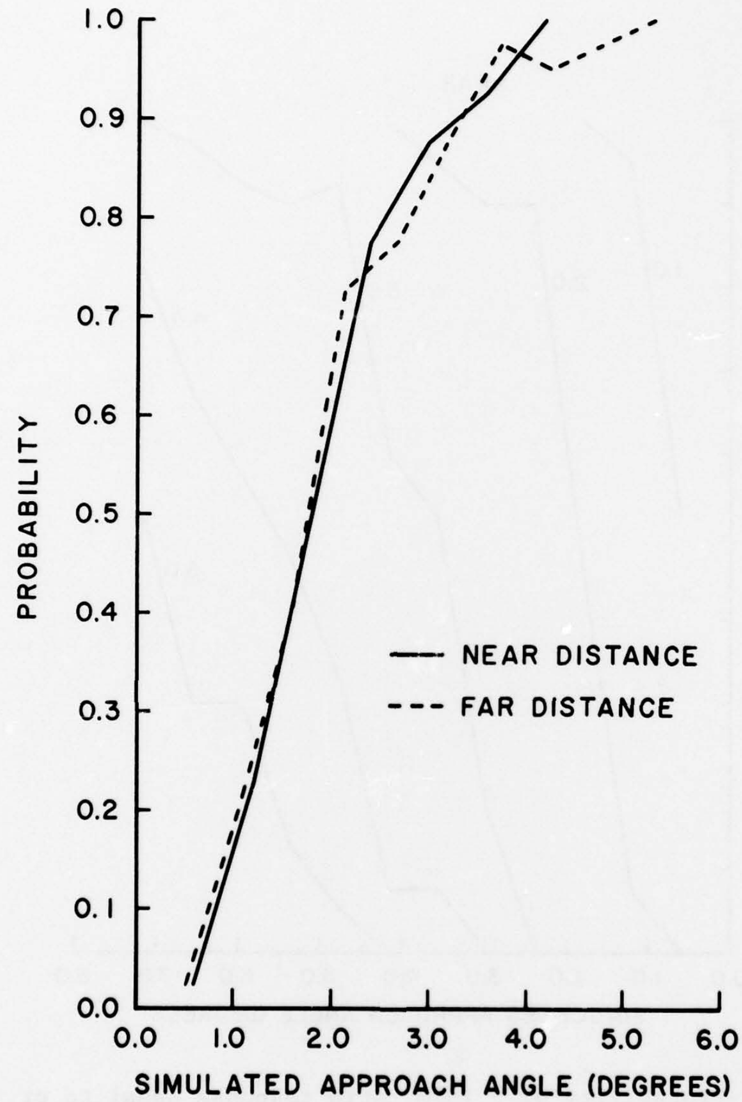

Figure 20. Probability of a category response equal to or greater than "OK" as a function of simulated approach angle at both near (8,000 ft) and far (26,000 ft) distances.

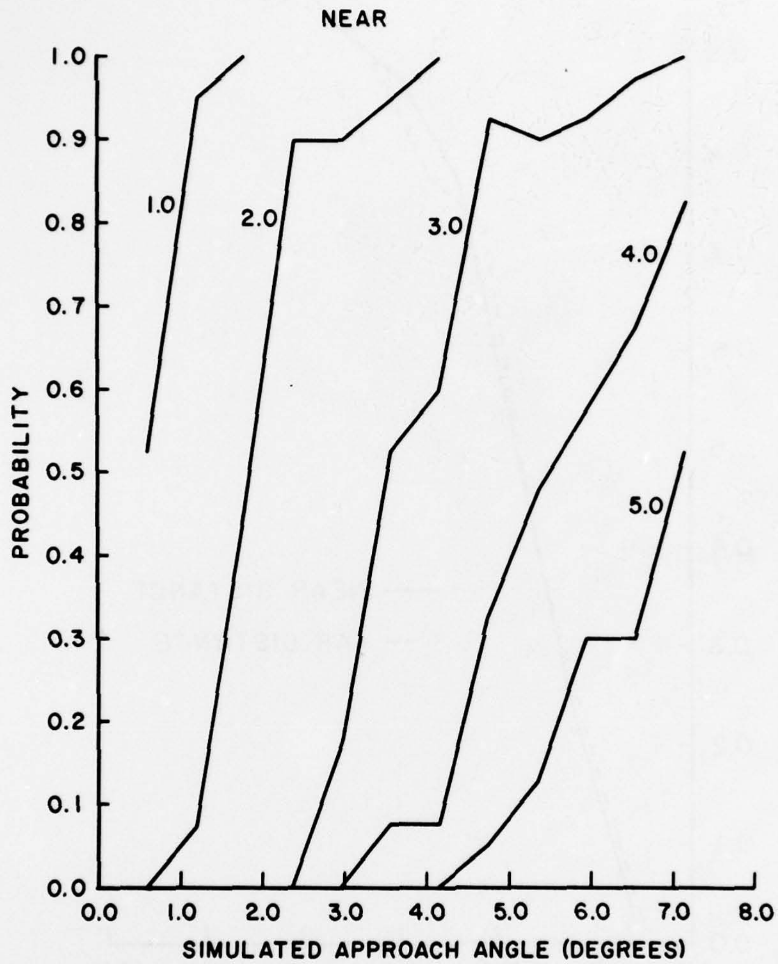

Figure 21. Probability of a form ratio response equal to or greater than numerical values 1 through 5 as a function of simulated approach angle at the near (8,000 ft) distance.

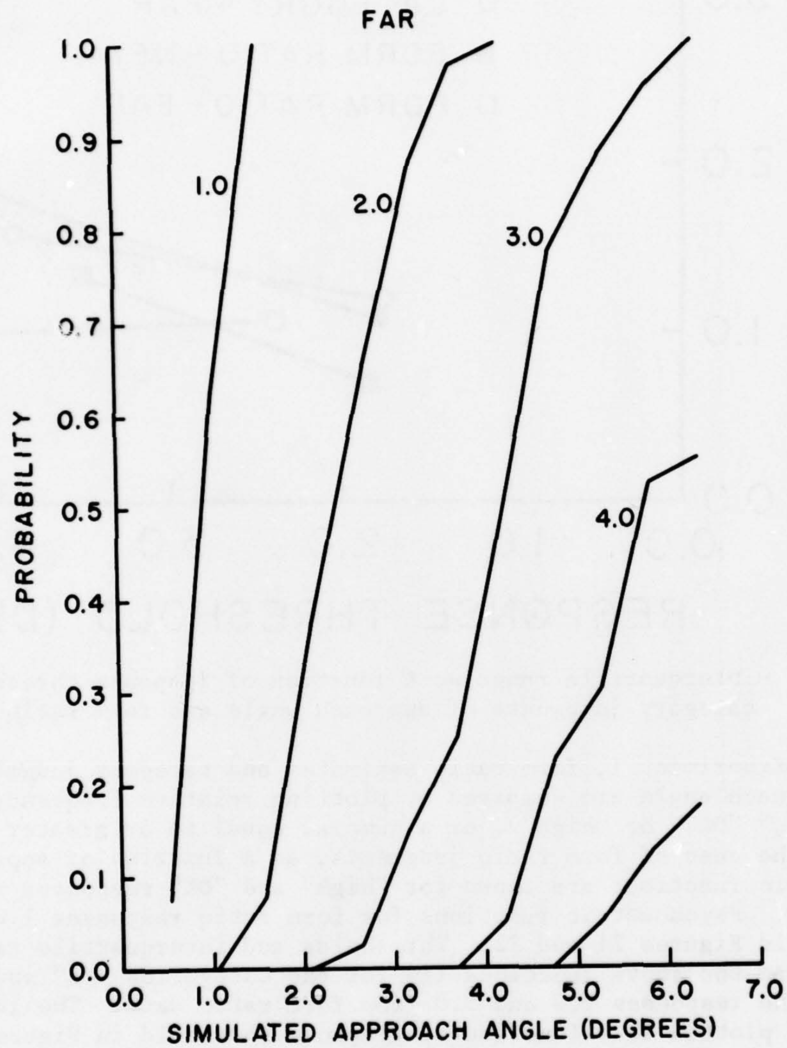

Figure 22. Probability of a form ratio response equal to or greater than numerical values 1 through 5 as a function of simulated approach angle at the far (26,000 ft) distance.

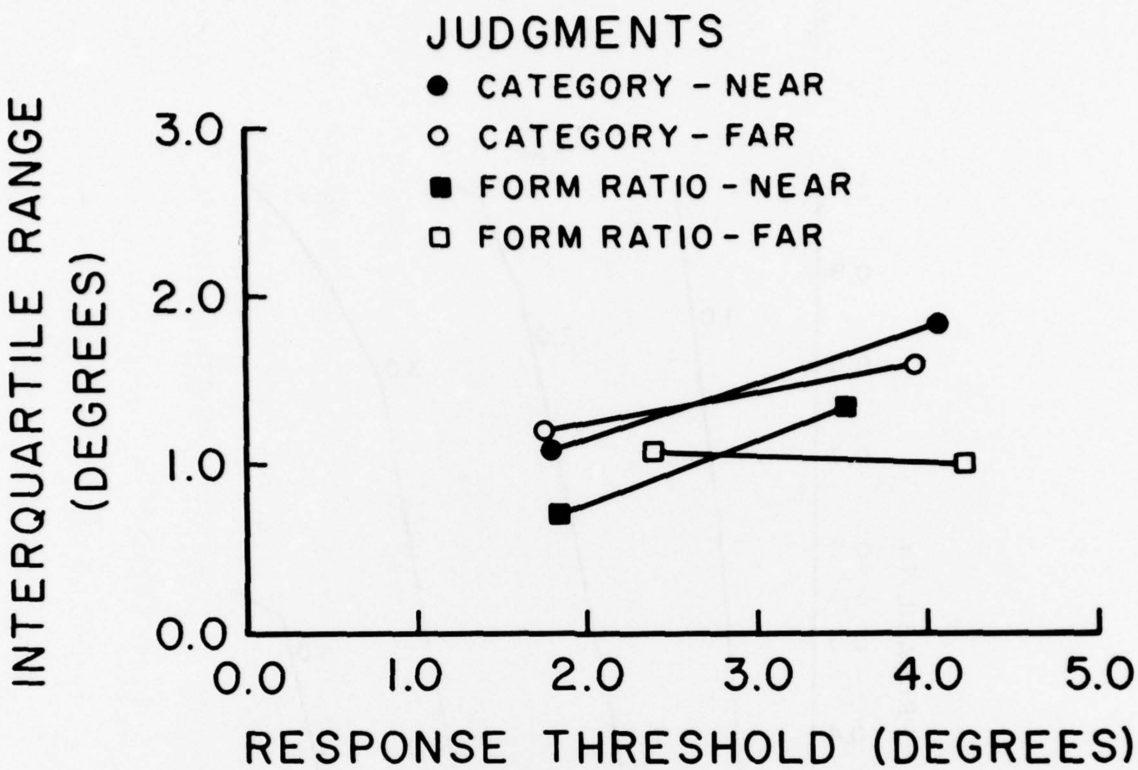

Figure 23. Interquartile range as a function of response threshold for category judgments of approach angle and form ratio judgments.

As in Experiment I, form ratio estimates and category judgments of simulated approach angle are compared by plotting relative frequency of a category ("low," "OK," or "high"), or a numeral equal to or greater than a certain value in the case of form ratio judgments, as a function of approach angles. Psychometric functions are shown for "high" and "OK" responses in Figures 18, 19, and 20. Psychometric functions for form ratio responses 1.0 through 5.0 are shown in Figures 21 and 22. Thresholds and interquartile ranges were derived from the above functions (i) for the categories "OK" and "high" and (ii) for the responses 2.0 and 3.0 from form ratio data. The interquartile ranges are plotted as a function of response threshold in Figure 23. There is a tendency for response variability, as measured by the interquartile range, to increase as response threshold increases, with the exception of form ratio responses at the far distance. Response variability is also lower for a given magnitude of response threshold in form ratio estimates than in category judgments of approach angle, in contrast to the finding of Experiment I.

Dynamic Condition. Responses for all tasks of the dynamic condition were measured continuously in terms of the generated approach angle to threshold

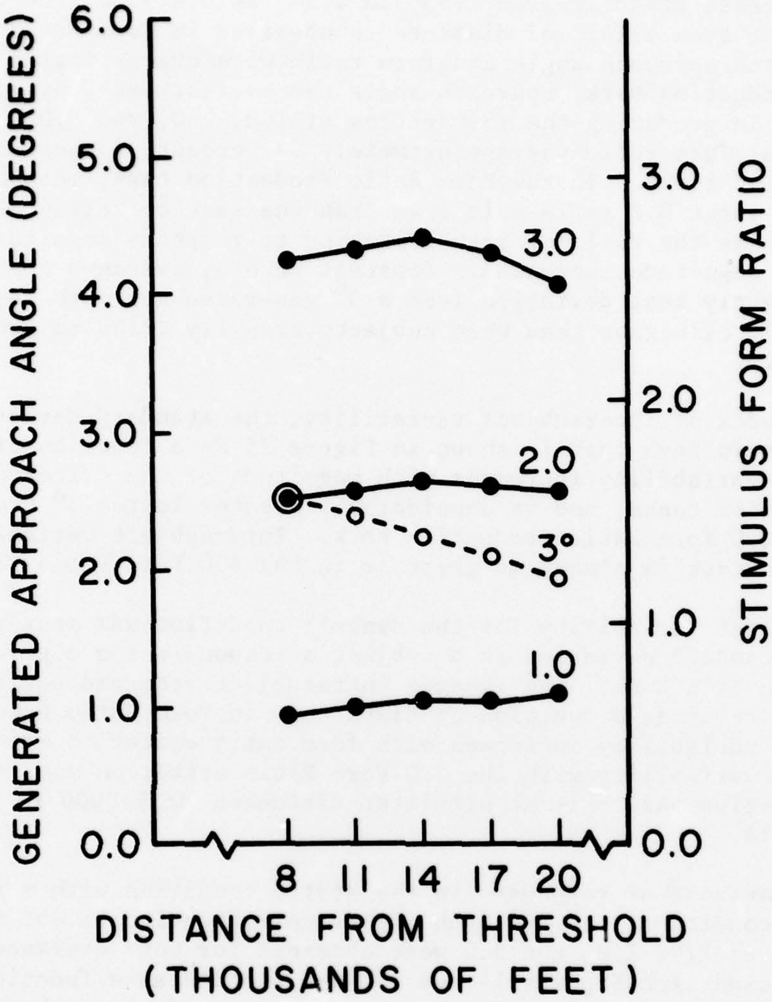

Figure 24. Generated approach angle in the dynamic condition as a function of distance for the three form ratio production tasks and the 3^{o} approach angle production task.

throughout each simulated approach as in Experiment I. Generated approach angles over the distance range of 20,000 ft to 8,000 ft from threshold were analyzed. Mean generated approach angle is shown as a function of distance for each task in Figure 24 for the specific distances of 8,000, 11,000, 14,000, 17,000, and 20,000 ft from threshold. Since actual form ratio is related to generated approach angle (for angles up to 10^{o}) by the same linear function at all distances, corresponding values of form ratio generated in these responses can be read on the ordinate at the right side of Figure 24. In the 3^{o} Production responses, generated approach angles averaged over all

subjects increase steadily from 1.93° to 2.54° as distance from threshold decreases. No such effect of distance is observed in Form Ratio Production responses; both approach angle and form ratio were overestimated in all cases. In the 3° Production task, approach angle was overestimated by approximately 33 percent. In producing the form ratios of 1.0, 2.0, and 3.0, overestimation of actual form ratio was approximately 54 percent, 25 percent, and 13 percent, respectively. In the Form Ratio Production task, responses were consistently about 0.6 ratio unit less than the task criterion, so overestimation (taken as the ratio of task criterion to response magnitude) decreased as criterion magnitude increased. Constant errors, averaged over distance, indicate slightly less deviation from a 3° generated approach angle with the 2.0 form ratio criterion than when subjects actually tried to produce a 3° approach angle.

For an index of intersubject variability, the standard deviation of subject means in each task is shown in Figure 25 as a function of distance. Intersubject variability increases with magnitude of the criterion in Form Ratio Production tasks, and is considerably greater in the 3° Production task than in the 2.0 Form Ratio Production task. Intersubject variability in the 3° Production task is almost as great as in the 3.0 Form Ratio task.

Intrasubject variability for the dynamic condition was measured by calculating the standard deviation in a subject's responses for a given task over all trials in each task. The average intrasubject standard deviation is shown in Figure 26 as a function of distance. In Form Ratio Production tasks, intrasubject variability increases with form ratio criterion magnitude, but intrasubject variability with the 2.0 Form Ratio criterion was less than in the 3° Production task only at simulated distances of 11,000 to 8,000 ft from threshold.

For comparisons of responses in the static condition with responses in the dynamic condition, the approach angles corresponding to estimated form ratio values of 1.0, 2.0, and 3.0 were obtained for both distances in the static condition from Figures 14 and 15, and plotted as a function of distance in Figure 27 along with the average value of approach angles judged "OK" at each distance. Overestimation of form ratio in these plots of static data was slightly, but consistently greater at the near distance, contrary to the dynamic condition. However, those approach angles in the static condition which were associated with estimated form ratios of 1.0, 2.0, and 3.0 predict the responses of the dynamic condition fairly well with the exception of the distance effect that occurred in the static condition. The average approach angle judged "OK" in the static condition is consistently higher by almost 1° than the average approach angle generated in the dynamic 3° Production task. In the static situation, the mean simulated approach angle judged "OK" was higher at the near distance than at the far distance, in agreement with 3° Production responses.

Of particular interest is the comparison of 3° Production responses and the 2.0 Form Ratio Production responses, since the latter would yield a

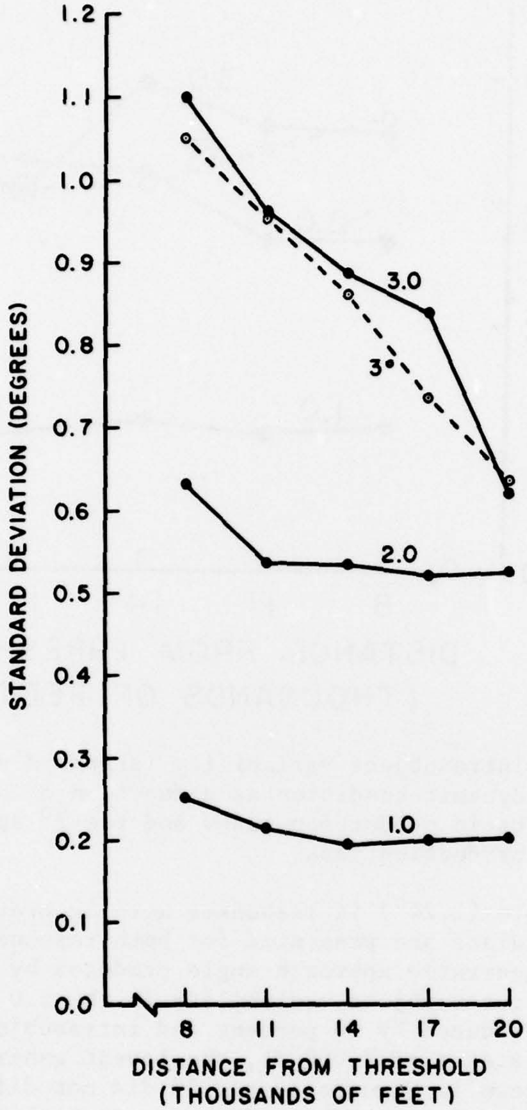

Figure 25. Intersubject variability (standard deviation) in the dynamic condition as a function of distance for the three form ratio production tasks and the 3° approach angle production task.

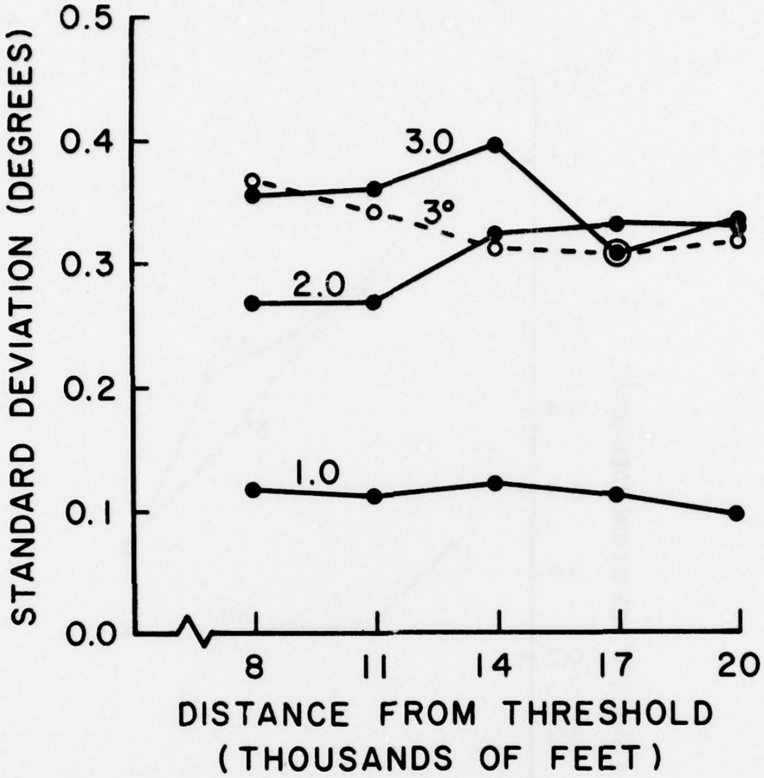

Figure 26. Intrasubject variability (standard deviation) in the dynamic condition as a function of distance for form ratio production tasks and the 3^{o} approach angle production task.

similar approach angle (3.24^{o}) if responses were accurate. In Figures 28 and 29, means and medians are presented for both responses as well as the highest and lowest generated approach angle produced by any subject at each distance. Although intersubject variability in the 2.0 Form Ratio Production task was reduced by 40 percent and intrasubject variability by 27 percent at the distance of 8,000 ft, the lowest generated approach angle by any subject as shown in Figures 28 and 29 did not differ greatly in 3^{o} Production and 2.0 Form Ratio tasks. The lower variability in the form ratio responses is associated with reduced extreme deviations above the mean at all distances and smaller extreme deviations below the mean at distances greater than 11,000 ft from threshold.

Mean generated approach angles in the 2.0 Form Ratio Production task and the 3^{o} Production task at the 8,000, 11,000, 14,000, 17,000, and 20,000 ft distances were compared in a split-plot factorial analysis of variance. Order of task presentation (3^{o} first vs. 2.0 first) was the between-groups

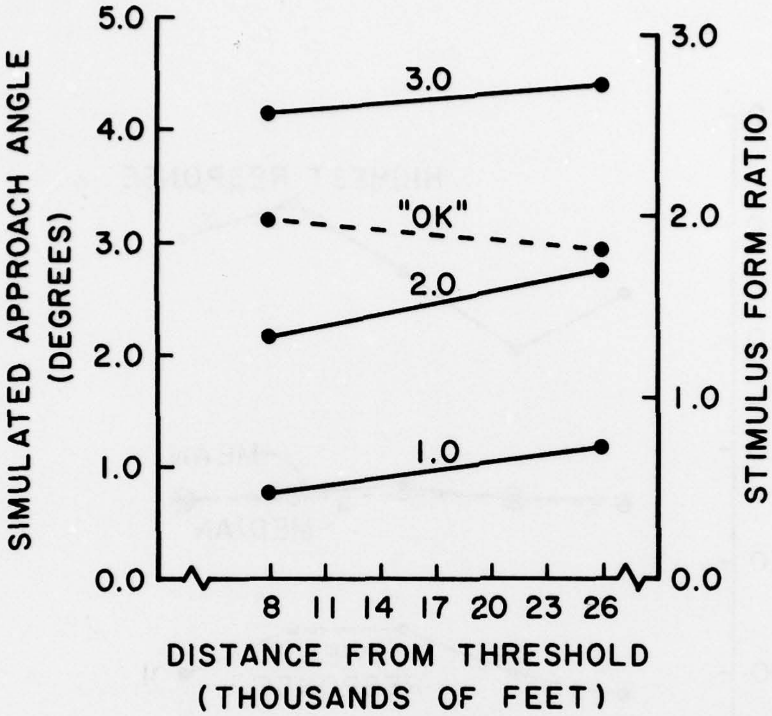

Figure 27. Mean simulated approach angles in the static condition eliciting form ratio judgments of 1.0, 2.0, and 3.0 and the "OK" category of estimated approach angle.

variable; task and distance were the within-group variables. The only significant effect was the main effect of distance ($p < .01$). Individual comparisons of cell means in that interaction revealed that generated approach angles were significantly higher in the 2.0 Form Ratio Production task at simulated distances of 14,000 ft and greater. The main effect of distance was found to be significant only in the 3° Production task. Although generated approach angles tended to be higher in the subjects given form ratio judgments first, the effect of order was not significant ($.05 < p < .10$). The effect of order on 3° Production responses will be further discussed below.

The standard deviation of a subject's responses over repetitions for a given task, as discussed above, was used as an index of intrasubject variability. Intrasubject variability was analyzed in a split-plot analysis of variance as a function of order of task presentation, task, and distance.

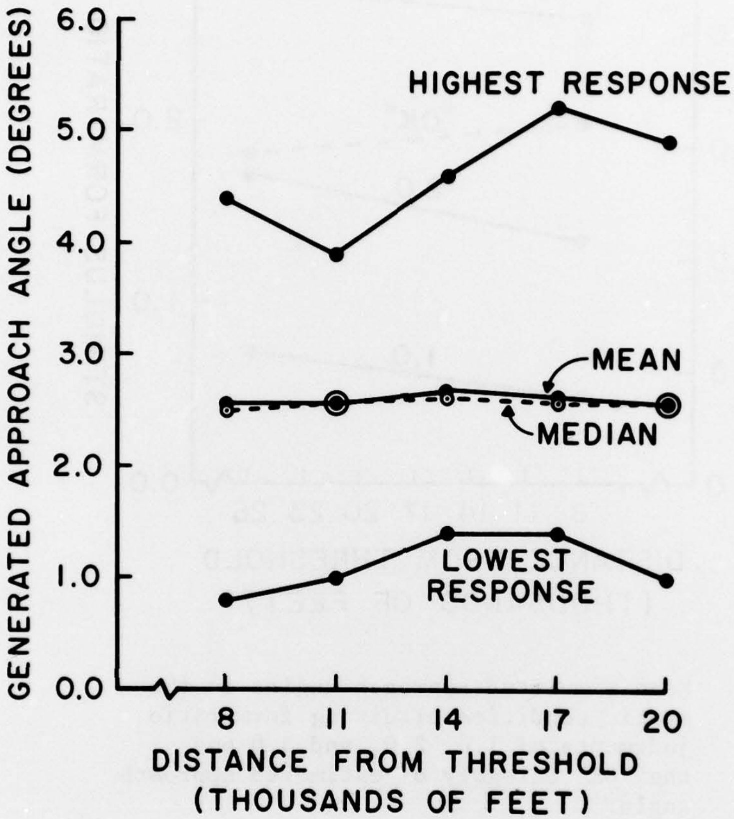

Figure 28. Mean, median, and range of responses in the 2.0 form ratio production task.

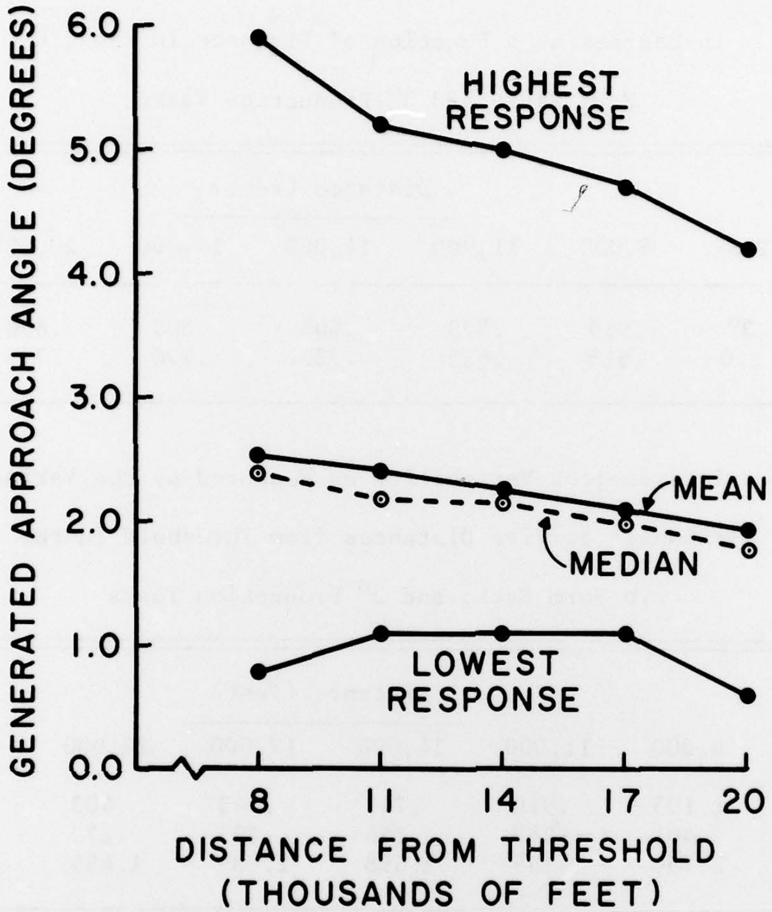

Figure 29. Mean, median, and range of responses in the 3° approach angle production task.

No significant effects were observed in this analysis. Although intrasubject variability was lowest at near distances in the 2.0 Form Ratio Production task, as shown in Figure 26, the effect of task was not significant nor was the interaction of task with distance. Intrasubject variability was also examined using the range of a subject's responses over repetitions in the two tasks. Again, ANOVA revealed no statistically significant effects of task, distance, or order, although the intrasubject range of responses tended to be less in the 2.0 Form Ratio Production task than in the 3° Production task as shown in Table 2.

Intersubject variability, as mentioned above, was consistently less in the 2.0 Form Ratio Production task than in the 3° Production task. Intersubject variability is compared in Table 3 in terms of the variance among individual

TABLE 2. Intrasubject Range of Generated Approach Angles in Degrees as a Function of Distance in the 2.0 Form Ratio and 3^{o} Production Tasks

Task	Distance (feet) 8,000	11,000	14,000	17,000	20,000
3^{o}	.915	.875	.805	.800	.830
2.0	.615	.635	.735	.770	.715

TABLE 3. Intersubject Variability as Measured by the Variances of Responses at Five Distances from Threshold in the 2.0 Form Ratio and 3^{o} Production Tasks

Task	Distance (feet) 8,000	11,000	14,000	17,000	20,000	Mean
3^{o}	1.105	.910	.743	.543	.403	.741
2.0	.401	.289	.286	.273	.277	.305
Ratio	2.756	3.149	2.598	1.989	1.455	2.430

subjects of mean generated approach angle in the two tasks at each of five distances. In both tasks intersubject variability increased as simulated distance from threshold decreased. Variability of response was consistently higher in the 3^{o} Production task and the average ratio of variance in that task to variance in the 2.0 Form Ratio Production task is 2.43. Differences in the magnitude of variances in the two tasks cannot be evaluated by the conventional F-ratio due to lack of independence of scores in the two tasks. Statistical comparison of intersubject variability on the 2.0 Form Ratio and 3^{o} Production tasks was, therefore, performed by converting the mean generated approach angle for a given subject to an absolute deviation from the group mean at each of the following simulated distances from threshold: 8,000, 11,000, 14,000, 17,000, and 20,000 ft.

A split-plot analysis of variance was used to examine the effects of task order, task, and distance on this measure of intersubject variability. The only significant effects were the main effect of distance ($p < .001$) and the

interaction of task with distance ($p < .025$). As shown in Table 4, absolute deviations of individual means from the group mean for a particular task and distance were 60 percent larger, on the average, in the case of the 3° Production task. This effect of task on intersubject variability increased as distance from threshold decreased. Comparisons of individual means in the interaction of task with distance indicate that intersubject variability was significantly less in the 2.0 Form Ratio task at the 8,000 ft and 11,000 ft distances.

TABLE 4. Absolute Deviations in Degrees of Individual Means From the Group Mean as a Function of Distance in the 2.0 Form Ratio and 3° Production Tasks

	Distance (Thousands of feet)					
Task	8	11	14	17	20	Mean
2.0	.44	.37	.35	.37	.40	.39
3°	.75	.75	.63	.54	.46	.63

As discussed above, the 3° Production task was administered in the present experiment (i) following form ratio judgments in static and dynamic trials with half the subjects, and (ii) prior to those form ratio trials with the other half of subjects. In a previous study (26), 3° Production responses were obtained following a series of dynamic trials on which pilots adjusted the model to appear horizontal (parallel to the floor). These three treaments were evaluated regarding effects on generated approach angles in the 3° Production task. Data from the earlier study (26) were reported in terms of generated approach angles to the midpoint of the touchdown zone. Generated approach angles to threshold were calculated from those data for comparison with data of the present experiment. The mean generated approach angles to threshold are shown in Table 5 as a function of prior experience and distance. Responses were averaged over each of the two 1-mile segments of simulated approaches between 20,000 and 8,000 ft from threshold for this analysis.

Generated approach angles were highest (2.57°) in the group which had Form Ratio Production first, next highest (1.99°) in the group which had the 3° Production task prior to any other task, and lowest (1.72°) in the group from the earlier experiment which had horizontal adjustment trials first. The responses of the three groups were compared statistically in a split-plot analysis of variance with prior task as the between-groups variable and distance as the within-group variable. The main effect of prior task was significant ($p < .05$) as was the main effect of distance ($p < .01$). The interaction of the two variables was not significant. Individual comparisons of means at each distance interval indicated that the mean generated approach angle in the "form ratio first" group was significantly higher than the mean generated approach angle in the "horizontal first" group at both the near ($p < .01$) and far ($p < .05$) distance intervals. The mean generated approach angle in the group given the 3° Production task first was intermediate, but was not significantly different from the means of either the "form ratio first" group or the "horizontal first" group.

TABLE 5. Generated Approach Angle in Degrees in the 3° Production Task as a Function of Task Order and Distance

	Task Order		
Distance	Form Ratio First	3° First	Horizontal First
8,000-14,000 ft	2.76	2.12	1.71
14,000-20,000 ft	2.38	1.85	1.72
MEAN	2.57	1.99	1.72

Discussion.

Approach Angle Responses. The great variability in judgments of approach angle in both dynamic and static conditions was the principal finding, as in Experiment I. Of particular importance is the fact that simulated approach angles as low as 0.5° were judged acceptable for approach to landing in static trials and angles as low as 0.8° were produced in the 3° task of the dynamic condition. The importance in the aviation situation of the occasional acceptance of such extremely low approach angles as safe is clear. A pilot only has to crash short of the runway once in his career to destroy his and his passengers' lives! This acceptance of dangerously low approach angles in both static and dynamic cases reinforces previous warnings of limited ability to judge approach angle accurately in the nighttime "black hole" situation (26).

Although variability of responses was perhaps the most important finding, constant errors in the dynamic 3° Production task corroborate previous findings (26) that angles of approach are overestimated in nighttime

approaches. The present study extends this finding to show that the magnitude of overestimation is influenced by prior experience in visual tasks performed with the runway model and that overestimation increases with distance. The comparison of responses in the 3^o Production task as a function of prior task performance showed that generated approach angles tended to be about 0.5^o higher when they followed form ratio estimations than when the 3^o Production task was given first. In contrast, prior participation in the horizontal adjustment task of the earlier experiment (26) lowered responses about 0.25^o relative to the "no prior task" condition. Two possible causes of such effects of prior tasks are suggested. Adaptation level theory would predict that the range of stimuli shown prior to the 3^o Production task would affect subsequent judgments in the 3^o task by its effect on adaptation level as discussed above. Simply seeing the wide range of angles in the form ratio tasks would elevate adaptation level, and exposure to consistently low angles of approach in the horizontal orientation task (26) would lower adaptation level. Apparent magnitude of approach angle would be judged relative to adaptation level and, therefore, would shift with adaptation level. These effects of prior tasks should be reexamined. If adaptation level theory does apply to the process of judging approach angles, the phenomenon of a shift in adaptation level might provide a useful technique for evaluating the importance of the possible cues for judging an approach angle. Cues such as linear perspective and form ratio could be varied independently in trials on which subjects simply observed models at selected values of simulated approach angle. The magnitude of the effects of their prior experience on responses in a subsequent 3^o Production task would indicate the relative importance of the particular cue varied in "adaptation" trials.

A second possible mechanism for effects of prior tasks upon subsequent performance in the 3^o Production task is response bias. Response bias might involve a sequence effect similar to that described by Baird and Noma (1) and others (19,29) in which a response tends to be assimilated toward the value of the immediately prior response without awareness of the observer. Future research should attempt to determine if the effect of prior tasks is valid and, if so, whether stimulus effects on adaptation level or response effects are involved. If effects of prior experience exist based on simple exposure to the runway without feedback, they would suggest an important interaction between successive approaches. For example, a low approach would be predicted following a previous low approach if negative feedback was not obtained.

Form Ratio Estimates. Actual form ratio in static and dynamic trials was overestimated on the average, with the ratio of estimated to actual form ratio decreasing systematically as actual form ratio increased. This decrease in relative magnitude of constant errors with increasing stimulus magnitude is most likely due to decreasing shape constancy as a result of changes in linear perspective in the runway image as discussed in Experiment I. The effect of distance on form ratio estimates, slightly less overestimation at the farther distance, is also probably due to shape constancy. For a given simulated angle, linear perspective increased with distance causing a decrease in shape

constancy. The slight decrease at the far distance in static trials in the mean simulated approach angle judged "OK" might also be related to changes in linear perspective as a function of distance. This would be expected if pilots used a constant criterion of linear perspective in the image.

Verbal estimates of form ratio and category judgments of approach angle both exhibited considerable variability in the static condition. The comparison of these two types of judgments in terms of interquartile ranges of psychometric functions indicated slightly lower variability, and therefore, more precise discrimination of simulated approach angles when form ratio was being judged. This effect was not large, however. Considering the contrary finding of Experiment I and the variability of form ratio estimates, it must be concluded that responses in the static condition do not support the hypothesis that estimates of form ratio can supplement judgments of approach angle.

Comparison of 2.0 Form Ratio and 3^{o} Production Tasks. The comparison of performance in the 3^{o} Production task and the 2.0 Form Ratio task is of particular interest since accurate performance in both tasks would have produced an approach angle of close to 3^{o}. Regarding constant deviation errors from the desired 3^{o} approach angle, performance in the 2.0 Form Ratio task was superior at all distances but 8,000 ft. Although intrasubject variability was only slightly less in the Form Ratio task, intersubject variability was significantly less at nearer distances, from 11,000 to 8,000 ft from threshold. These findings suggest a small advantage for form ratio judgments, in terms of both constant and variable errors, although a much greater reduction of errors in generated approach angle is needed, from the point-of-view of aviation safety. In general, the above findings corroborate the earlier conclusion that the utility of form ratio judgments as a supplement for approach angle judgments is doubtful.

CHAPTER IV

OVERVIEW

The most important finding of the two present experiments is that judgments of approach angle were extremely variable in the nighttime approach situation when the only sources of visual information for vertical guidance were the cues in the runway image. Of particular significance is the fact that simulated approach angles as low as 0.5° were judged acceptable for approach to landing and angles as low as 0.6° were generated on occasion when pilots were attempting to produce a 3° approach angle. These low responses represent dangerously low angles of approach which could be catastrophic in actual approach situations. The lability of the perceptual process involved is further illustrated by the sensitivity of that process to the range of simulated approach angles seen in other tasks prior to the 3° Production tasks. Seeing low angles in the prior Horizontal Production task lowered the simulated approach angle perceived to be 3° and seeing a wide range of angles in the Form Ratio tasks increased the angle perceived to be 3°. In addition to the extremely low responses, the present findings also corroborate previous results in this laboratory (26) regarding a tendency to overestimate angles of approach less than 3°. Although it is sometimes stated that cues in the runway image formed by boundary-marking (edge) lights represent the minimum cues that a pilot needs for landing (31), the present findings suggest that these cues may often be insufficient for a safe approach to landing.

The present experimental tasks did not involve feedback and, therefore, simulated the case of judging approach angle at an unfamiliar airport. Hasbrook, Rasmussen, Willis, and Connors (17) studied actual night and day visual approaches made by highly experienced professional pilots without the aid of an altimeter or any landing aid. All approaches were made to the same large, familiar, well-lighted airport located on the edge of a large city. Night approaches averaged about 100 ft lower than day approaches, but the most pronounced difference between the distributions of day and night approaches was that the extremely low approaches were much lower at night. Hasbrook et al. reported flight path data in terms of altitude as a function of time before reaching the middle marker. Calculations of generated approach angles for distances of 8,000 and 20,000 ft from threshold for these data are based on an assumed airspeed of 112.5 knots (which was the average in Hasbrook's study) and indicate extremely low approach angles of 1.6° and 1.4°, respectively, at those distances. These are at best approximations based on measurements from graphs, but they indicate that even with a familiar runway undesirably low approach angles can occur at night without the pilot's awareness. The present study indicates that even lower and more dangerous angles of approach can occur when descending toward an unfamiliar runway.

The form ratio cue discussed above could, theoretically, provide a basis for assessing approach angle based on the simple ratio of two angles subtended in the retinal image, the runway height and width of the far end. Responses involving apparent form ratio, however, did not indicate

significantly better identification or discrimination of simulated approach angles than did responses involving apparent magnitude of the approach angle. The present findings, especially that of similar intrasubject variability in form ratio and approach angle responses, do not support previous suggestions in the literature (22,31) that direct attention to form ratio can supplement or improve judgments of approach angle. The present findings do not eliminate the possibility that form ratio may operate as a cue at an unconscious level in the determination of perceived angle of approach. In support of this is the fact that, on the average, estimated approach angle varied as a linear function of estimated form ratio. If it is a cue, it is ineffective in reducing variability of approach angle judgments to an acceptable level. The possibility discussed above (that form ratio judgments may be used to compensate for constant approach angle errors in a particular pilot by empirically measuring the perceived form ratio associated with the correct approach angle for a particular runway) should be tested. The present findings suggest that such a procedure might be helpful since individual differences in responses were substantial.

Linear perspective was shown to be a cue of importance since it was directly associated with errors in judgments of approach angle and form ratio and, therefore, should receive future attention. Since the function relating linear perspective to approach angle varies with distance, future research should study how the apparent magnitude of linear perspective and apparent distance are related to judgments of approach angle.

The present study reinforces previous warnings of the danger in night visual approaches and gives evidence of even greater danger in the case of an unfamiliar runway. The occurrence of undetected extremely low approaches at night indicates a need for improved training for night approaches with emphasis on the generalization of experience to unfamiliar airports. There is also great need for night landing aids such as Instrument Landing Systems (ILS) and Visual Approach Slope Indicator (VASI) systems at all airports where, otherwise, lack of surrounding ground lights may force reliance upon the ineffective visual cues in the runway image for visual approaches.

Although the process of perceiving approach angle at night remains obscure, the present findings as well as others (30) point to the importance of linear perspective as a significant determinant in the nighttime approach situation. The importance of the form ratio cue is unclear, although conscious attention to this cue is of questionable value based on present findings. In any event, the evidence concerning response variability points to the danger of reliance on visual information in the nighttime approach situation commonly called the "black hole" where only runway lights on the ground are visible. The daytime approach situation is, in contrast, thought to be relatively safe and as mentioned above, Hasbrook et al. (17) have shown that extreme deviations below the desired glide path are reduced in the daytime.

Suggestions for Future Research. The present findings suggest that the important difference between visual information in day and night situations

lies in the lack of visual detail in the scene in addition to the runway image. In order to determine the cues necessary for reliable visual judgments of approach angle at night, future research should manipulate those extra-runway cues. Kraft (20) has shown the importance of lights of a simulated city on sloping terrain behind a runway in causing approach angle errors. Future research should vary visual detail in the nighttime scene in front of the runway, i.e. details or lights on the ground along and to the side of the approach path to the runway. Approach lights in front of the runway in the present simulation did not prevent illusions from occurring at simulated distances from threshold of 8,000 ft and greater. The effects of position and quantity of objects and lights on the ground both at greater distances in front of the runway and closer to the simulated aircraft position should be studied. The effect of adding familiar objects to the scene should also be studied. Although the problem of varying the amount of information in the scene may be most easily performed in the laboratory or by using a modern computer-controlled aircraft simulator with a visual display, there remains the need for operational study of the distributions of generated flight paths in both day and night visual approaches as a function of a variety of environmental and atmospheric factors to determine the validity of simulation studies. The present findings suggest a special need to extend the Hasbrook et al. study (17) of day and night approaches to the case of an unfamiliar airport and to the "black hole" condition in the nighttime case. Future studies of generated approach angles in night visual approaches should also include both stable and unstable (turbulence) conditions and give specific attention to the utility, or lack of utility, of the "gunsight" technique discussed above.

Since most night visual approaches are performed safely, pilots must either successfully correct for visual illusions or visual illusions do not normally completely erase the margin for error that usually exists. However, approach angle errors of the magnitude observed in the present experiments can drastically reduce the altitude safety margin and increase dangers posed by other problems, such as downdrafts, windshears, power failures, etc., by reducing the amount of altitude and, hence, time available for recovery. Therefore, the perceptual process by which pilots fly night approaches should be further studied so that we may (i) understand wny this process occasionally but tragically fails, and (ii) find means of preventing such failures in the future.

CHAPTER V

Summary.

Landing an aircraft at night when only runway lights are visible, an environment often called the "black hole," is one of the most dangerous phases of flight. The visual cues found in the nighttime runway image are commonly listed as size and shape cues, relative motion parallax, and image intensity gradients. Previous experiments in this laboratory have shown that relative motion parallax is ineffective as a cue for judgment of approach angle. The present study examined another potential shape cue in the runway image, called form ratio, which has received little attention in the literature. Form ratio has also been called perspective (not to be confused with linear perspective) and is defined as the ratio of vertical height of the runway to width of the far end of the runway in the retinal image. The form ratio associated with a given approach angle is constant over distance and varies only as a linear function of actual runway length-width ratio. The form ratio cue could, theoretically, provide a basis for assessing approach angles based on perception of the simple ratio of size in two parts of the runway image. The ability to judge form ratios was examined and compared with the ability to judge approach angles in the nighttime "black hole" situation in two experiments.

High response variability was found both in verbal judgments of approach angles and in productions of the 3^{o} approach angle, along with a general tendency to overestimate the magnitude of approach angles less than 3^{o}. These response tendencies frequently led to acceptance of angles of less than 1.0^{o} as "OK" which in actual approaches would have a high probability of resulting in crashes short of the runway.

Estimation and production of form ratios in the runway image were also quite variable and indicated consistent overestimation of form ratio magnitude. Intersubject and intrasubject variability of form ratio and approach angle responses was comparable. The present findings do not support the utility of form ratio judgments as an aid in selecting approach angle.

The present findings provide empirical evidence of visual illusions and the danger of reliance on visual information for judgments of approach angle in the nighttime "black hole" situation where only runway lights are visible on the ground. They also suggest that the important visual deficit at night lies in lack of visual detail in the scene outside the runway image. Future research should focus on the effects of position, quantity, kind of objects, and extra-runway lights in the night visual approach scene on judgments of approach angle and attempt to validate laboratory findings in operational studies of actual approaches to landing.

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